An Integrated Biogeographic Assessment of Reef Fish Populations and Fisheries in Dry Tortugas: Effects of No-take Reserves

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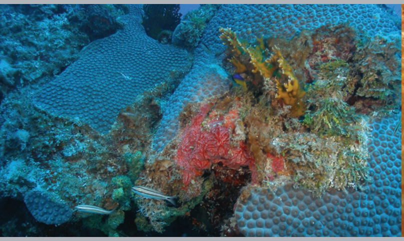

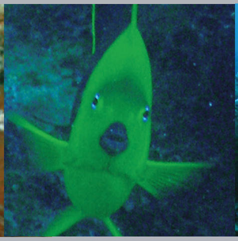

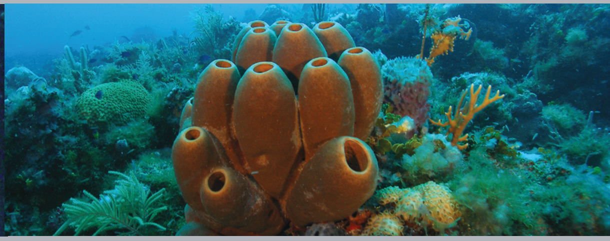

August 2012

NOAA TECHNICAL MEMORANDUM NOS NCCOS 111

NOAA NCCOS Center for Coastal Monitoring and Assessment

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August 2012

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NOAA Technical Memorandum NOS NCCOS 111

Citations

Citation for entire document:
Jeffrey, C.F.G., V.R. Leeworthy, M.E. Monaco, G. Piniak, M. Fonseca (eds.). 2012. An Integrated Biogeographic Assessment of Reef Fish Populations and Fisheries in Dry Tortugas: Effects of No-take Reserves. NOAA Technical Memorandum NOS NCCOS 111. Prepared by the NCCOS Center for Coastal Monitoring and Assessment Biogeography Branch. Silver Spring, MD. 147 pp.

Example citation for an individual chapter:
Jeffrey, C.F.G., L. Jiangang, J.S. Ault, S.G. Smith, V. Ransibrahmanakul. 2012. Physical and Oceanographic Features of the Tortugas Ecological Reserve Study Area. pp 7-20. In: C.F.G. Jeffrey, V.R. Leeworthy, M.E. Monaco, G. Piniak, M. Fonseca (eds.). 2012. An Integrated Biogeographic Assessment of Reef Fish Populations and Fisheries in Dry Tortugas: Effects of No-take Reserves. NOAA Technical Memorandum NOS NCCOS 111. Prepared by the NCCOS Center for Coastal Monitoring and Assessment Biogeography Branch. Silver Spring, MD. 147 pp.

Acknowledgements
The editors and authors would like to thank the many contributors to this report. Their efforts to review, edit, design and format the document are greatly appreciated. Many thanks to: Chris Caldow, Alicia Clarke, Kimberly Edwards, Jamison Higgins, Sarah D. Hile, Todd Kellison, Kevin McMahon and Sam Tormey.

The covers for this document were designed and created by Gini Kennedy (NOAA). Cover photos were provided by NCCOS Center for Coastal Fisheries and Habitat Research and NCCOS Center for Coastal Monitoring and Assessment's Biogeography Branch. Government contract labor was provided by CSS-Dynamac, Fairfax, VA under NOAA contract number DG133C11CO0019.

ABOUT THIS DOCUMENT

The Tortugas Integrated Biogeographic Assessment presents a unique analysis of demographic changes in living resource populations, as well as societal and socioeconomic benefits that resulted from Tortugas Ecological Reserves during the first five years after their implementation. Prepared by NOAA's National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment Biogeography Branch, this assessment is one of a series of such projects designed to provide managers with critical information on the distribution of marine resources under their jurisdiction.

Over the past decade, NCCOS has applied an integrated biogeographic assessment approach to inform the management of marine resources within both coral reefs and National Marine Sanctuaries since 1998. To date, nine Office of National Marine Sanctuaries (ONMS) sites and most of the coral reef ecosystems in U.S. states and territories have had some level of biogeographic characterization or mapping completed through this partnership. Nearly two dozen scientists, researchers and managers contributed to this biogeographic assessment. Partners include: NCCOS, ONMS, National Marine Fisheries Service, University of Miami and University of Massachusetts, Amherst.

The results of this ecological characterization are available online. For more information on this and similar projects visit the NCCOS web site, http://coastalscience.noaa.gov/, or direct questions and comments to:

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Executive Summary

Christopher F.G. Jeffrey[1,2] and Vernon R. Leeworthy[3]

The Tortugas Integrated Biogeographic Assessment presents a unique analysis of demographic changes in living resource populations, as well as societal and socioeconomic benefits that resulted from the Tortugas Ecological Reserves during the first five years after their implementation. In 2001, state and federal agencies established two no-take reserves within the region as part of the Florida Keys National Marine Sanctuary. The northern reserve (Tortugas Ecological Reserve North) was established adjacent to the Dry Tortugas National Park, which was first declared a national monument in 1935. The reserves were designed to protect a healthy coral reef ecosystem that supports diverse faunal assemblages and fisheries, serves as important spawning grounds for groupers and snappers, and includes essential feeding and breeding habitats for seabirds. The unique ecological qualities of the Tortugas region were recognized as far back as 1850, and it remains an important ecosystem and research area today.

The Dry Tortugas National Park and surrounding areas are home to coral reef ecosystems that support diverse faunal assemblages and fish. Photos: Dry Tortugas National Park.

The two main goals of the Tortugas Ecological Reserve Integrated Ecological Assessment were: 1) to determine if demographic changes such as increases in abundance, average size and spawning potential of exploited populations occurred in the Tortugas region after reserve implementation; and 2) whether short-term economic losses occurred to fishers displaced by the reserve. This project utilized a biogeographic approach in which information on the physical features (i.e., habitat) and oceanographic patterns were first used to determine the spatial distribution of selected fish populations within and outside the Tortugas Ecological Reserve. Before-and-after reserve implementation comparisons of selected fish populations were then conducted to determine if demographic changes occurred in reef fish assemblages. These comparisons were done for the Tortugas region and also for a subset of available habitats within the Tortugas Ecological Reserve Study Area. Social and economic impacts of the reserves were determined through: 1) analyses of commercial landings and revenues from fishers, operating in the Tortugas region before and after reserve implementation and 2) surveys of recreational tour guides. Analyses of the commercial landings and revenues excluded areas inside Dry Tortugas National Park because commercial fishing has been prohibited within park boundaries since 1992. Key findings and outcomes of this integrated ecological assessment are organized by chapter and listed below.

Physical and Oceanographic Features

- Various mapping activities conducted by several agencies were compiled as part of this assessment to create the most comprehensive and up-to-date bathymetric and benthic habitat maps of coral and hardbottom for the region. These map products have filled existing data gaps; served as the basis for spatially-explicit monitoring programs, including those discussed in subsequent sections of this report; and expanded the spatial extent of known coral reef and hard bottom to include Riley's Hump and Tortugas Bank, previously unknown areas within the Dry Tortugas, as well as other habitats found less than 33 m deep between the Marquesas and the Dry Tortugas.

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- Circulatory patterns confirmed by remote sensing and drifter buoy studies indicate that the Tortugas region supplies fish and invertebrate larvae to areas eastward along the Florida Keys to the West Florida Shelf and Florida's east coast.

- Analysis of sea surface temperature data from 1985-2000 indicated that extremely high (27.5°C) and low (20.5°C) temperature events occurred during seven of 15 years and persisted for several weeks at a time in the Tortugas region. These temperature anomalies along with storm events represent natural environmental variability that may have affected recruitment and ultimately the distribution and abundance of reef fishes in the Tortugas region (Ault et al. 2006a,b).

Reef Fish and Macroinvertebrates

- The Tortugas region as a whole likely experienced an early increase in the biomass of exploited species within a few years of the Tortugas Ecological Reserve implementation (Ault et al. 2006a,b; 2005a,b; and 2007).

- Researchers observed significantly greater abundance, frequency of occurrence, and shifts toward larger sizes of Black and Red Grouper and Mutton Snapper in the Tortugas Ecological Reserve North and throughout the wider Tortugas region within four to six years of its establishment (Ault et al. 2006a,b; 2007).

Benthic Communities

- The Tortugas Ecological Reserve showed consistently higher coral cover than the Dry Tortugas National Park and unprotected sites, suggesting that reef habitats within the reserve were initially of better quality that unprotected sites.

- Studies show an overall reduction in percent live coral cover in the reserve and other areas in the Tortugas region over a 15-year study period. Chronic declines in the spatial extents and abundance of living coral is unexplained but most likely resulted from the synergistic effects of episodic events (e.g., hurricanes and diseases), as well as human-associated stressors.

- Macroalgae were the most common biological component averaging 25-33% in a given year, while coral cover, though highly variable among sites, averaged 5-6%.

Reef and Shelf Nekton Assemblages

- Variations in fish species richness and total abundance over time were similar across management strata (i.e., reserve, park and areas outside). Additionally, there were no significant differences among management strata in the ranks of the 25 most abundant species, which suggests that fish assemblage composition inside the ecological reserve and park were not significantly different from that found outside.

- Preliminary evidence by Burton et al. (2005) show Mutton Snapper--a commercially valuable and exploited species--may have reformed aggregations in the Tortugas region, suggesting the possibility that the implementation of the Tortugas Ecological Study Area has increased Mutton Snapper by protecting both the individuals during non-spawning times, as well as the spawning aggregations.

- Yellowtail Snapper, another exploited species, showed increasing trends in abundance, biomass and size within the reserve. The disproportionate increase within the reserve suggests that it has effectively protected exploited fishes within its confines since establishment.

Social and Economic Effects on Commercial Fisheries

There have been many reports and journal articles addressing the social and economic (socioeconomic) impacts of marine protected areas (MPA) including marine reserves or no-take areas (Berman et al 2008, Holland 2000, Mascia 2003, and Sanchirico et al. 2007). Most of these case studies reported marginal or small changes in the total amount of social activity affected by the MPA. In the few cases where large changes were reported (e.g., New England Groundfish Closure) economic and social impacts were obvious. However, these previous efforts have not definitively addressed the question of what actually happens during and after implementation of an MPA. Moreover, these past efforts have focused on expected possible outcomes based on either theory or have modeled behavior of fishers based on reasonable assumptions. To actually determine the trajectory of social impacts, in most cases, requires a pre-post implementation assessment of an MPA. Here, we report several findings from our pre-post integrated assessment of the socioeconomic impacts of the Tortugas Ecological Reserve.

- People employed in commercial fishery activities did not experience any financial loss due to the implementation of the reserve in the short-term. Fishermen appeared to adapt to the reserve implementation by shifting effort away from the Tortugas area towards fishing grounds closer to their home ports. Increasing fuel prices also contributed to this shift. This finding is in sharp contrast to the published (theoretical and modeling) literature which assumes that for short-term losses (i.e. opportunity costs) will ensue for those who are displaced from marine reserves.

- Reef fish catch from the Tortugas area increased pre to post reserve implementation and continues on an upward trend. This outcome was markedly contrary to predicted outcome of losses to the fishers because the fishery was considered overfished based on available monitoring data. However, the observed increase in reef fish catch resulted from the ability of displaced fishermen to relocate to previously unfished areas that were not previously sampled by researchers, and therefore were not part of the initial fishery stock assessment for the Tortugas region. That upward trend in reef fish catch from the Tortugas area reflected the expansionary phase of a new fishery. The projection of losses in the initial reserve implementation assessment was based on the assumption of perfect knowledge by both the scientists and the fishermen. For the fishermen, we assume they knew all the available fishing grounds and the fishing choices they made in the pre-Tortugas Ecological Reserve period were the profit maximizing choices. In reality, fishermen did not have perfect knowledge and displacement from the reserve led them to discover new fishing grounds (necessity is the mother of invention). One caveat to this conclusion is that it is not known if fishermen are taking bigger risks in fishing new fishing grounds i.e., did they not fish theses new fishing grounds in the past not because they did not know about them, but because winds and tides or other factors made it more dangerous to fish (see See Pendleton et al., 2001).

- Pre and post analysis of three important fisheries—shrimp, lobster and King Mackerel—again show no losses to commercial fishermen as a result of the Tortugas Ecological Reserve. Shrimp and King Mackerel catch increased post establishment, while spiny lobster catch initially declined following implementation but later began an upward trend.

Social and Economic Effects on Recreational Fisheries

- Tortugas recreational fisheries likewise did not experience any financial losses due to the implementation of the reserve. Recreational fishermen relocated away from the larger Tortugas area opting to stay closer to their home port because the rising cost of fuel and the new grouper regulations made trips to the Tortugas less profitable.

- There is little evidence that suggest there has been a negative or positive economic impact of reserve designation on charter fishing and diving operations that operated in the study area prior to its creation or that the reserve has been an economic barrier to businesses.

The integration and analysis of historical and current biological, physical, chemical and economic data presented in this document represents the first effort to evaluate the impact reserve designation has on both the living marine resources of the Tortugas region and the people whose livelihoods are connected to them. The resulting maps and data products provide managers with an assessment of Tortugas Ecological Reserve efficacy to support and guide ecosystem-based management decisions. Where possible this document contains hyperlinks to related data and resources (indicated by blue text) that are directly accessible when viewing the document in PDF.

This assessment is the work of numerous scientists and researchers from the NOAA National Centers for Coastal Ocean Science, NOAA Office of National Marine Sanctuaries, University of Miami Rosenstiel School of Marine and Atmospheric Science, University of Massachusetts, Amherst Human Dimensions Research Unit, Florida Keys National Marine Sanctuary and National Park Service South Florida-Caribbean Network. For more information about this project, visit: http://ccma.nos.noaa.gov/ecosystems/coralreef/tortugas.aspx.

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Chapter 1: Introduction

Christopher F.G. Jeffrey[1,2] and Vernon R. Leeworthy[3]

INTRODUCTION AND BACKGROUND

This report summarizes the results of an integrated assessment of reef fishes and fisheries in the Tortugas region. The results from projects that monitored and assessed reef fish populations since the implementation of the Tortugas Ecological Reserve (TER) were integrated with those from socio-economic studies conducted before and after reserve implementation to determine existing or potential biological and human (societal) benefits or impacts resulting from the TER.

Established in 2001 by federal and state agencies as part of the Florida Keys National Marine Sanctuary (FKNMS), the TER was designed to protect a coral reef ecosystem that supports diverse faunal assemblages and fisheries in the Tortugas region (Figures 1.1 and 1.2; NOAA, 2000). At 391 km^2 (151 nm^2) in area, the reserve consists of two sections (Tortugas North and Tortugas South) that encompass two areas locally known as Sherwood Forest and Riley's Hump (Figure 1.3). The reserve closed all water and seafloor within its boundaries to all consumptive and extractive uses. Justifications for implementation of the TER included preservation of species richness, protection of important spawning areas and habitat for snapper, grouper and other commercially valuable species, and ensuring the health of fish stocks and the stability of commercial and recreational fisheries (NOAA, 2000). Furthermore, the Tortugas region was considered a source of biodiversity for the Florida Keys and southwest shelf of Florida; it had the healthiest coral in South Florida, at least when the TER was established (NOAA, 2000). The Tortugas region also has high connectivity to the Florida Keys and mainland due to the regional confluence of several major ocean currents (Lee and Williams, 1999; Yeung and Lee, 2002; Sponaugle et al., 2005).

Figure 1.1. The coral reef ecosystems of the Tortugas Ecological Reserve (TER) support a diverse faunal assemblage in the Tortugas. Photo: NCCOS Center for Coastal Fisheries and Habitat Research (CCFHR).

*Figure 1.2. A Cleaning Goby fish (*Elacatinus genie*; left). A school of Bar Jacks (*Carangoides ruber*) swims just above a coral formation (right). Photos: NCCOS CCFHR.*

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Additional protection of coral reef ecosystem resources in the Tortugas region was needed for several reasons. Evidence existed that suggested reef resources in the Tortugas were being threatened and stressed by anthropogenic factors. Commercial and recreational fishing in Tortugas had reduced the abundance, body size and spawning potential ratio of key taxa (i.e., groupers, snappers, hogfish and grunt) through serial overfishing that occurred over decades (Bohnsack et al., 1994; Schmidt et al., 1999; Ault et al., 2005a,b; Ault et al., 2006). For example, the average size of Black Grouper (*Mycteroperca bonaci*) caught by fishers in 1999 was 40% smaller (i.e., 4.1 kg) than the average size (i.e., 10.2 kg) caught in 1935. Although FKNMS regulations prohibited freighters more than 50 m in length from anchoring within its boundaries, other Tortugas areas then outside of the FKNMS (e.g., Rebecca Shoals and Riley's Hump) continued to experience damage from the anchors of such large vessels (NOAA, 2000). The anchor chains from these vessels typically are composed of 45-kg links and cause severe damage to benthic substrates and their associated fauna as they drag back and forth across the seafloor in response to movement of anchored vessels. In addition, resource managers were concerned that if left unchecked, drastic increases in human visitation to the region for recreational activities including day trips, bird-watching, and fishing would further intensify the effects of other stressors on fragile ecosystem resources. Such concerns were warranted because visitation to the Dry Tortugas National Park (DRTO) increased by 300% from 18,000 visitors in 1984 to 72,000 in 2000 (NPS, 2005).

Adjacent to and east of TER North is the DRTO (Figure 1.3). The park was first declared a national monument without any user restrictions in 1935, but protection for corals and other marine life was legislated in 1980 (NPS, 2005). In 1992, the DRTO was formally established by the National Park Service (NPS) who received jurisdictional and management responsibilities to protect 269 km^2 from commercial fishing. Federal regulations prohibited commercial fishing but allowed recreational fishing, boating, snorkeling, scuba diving and other

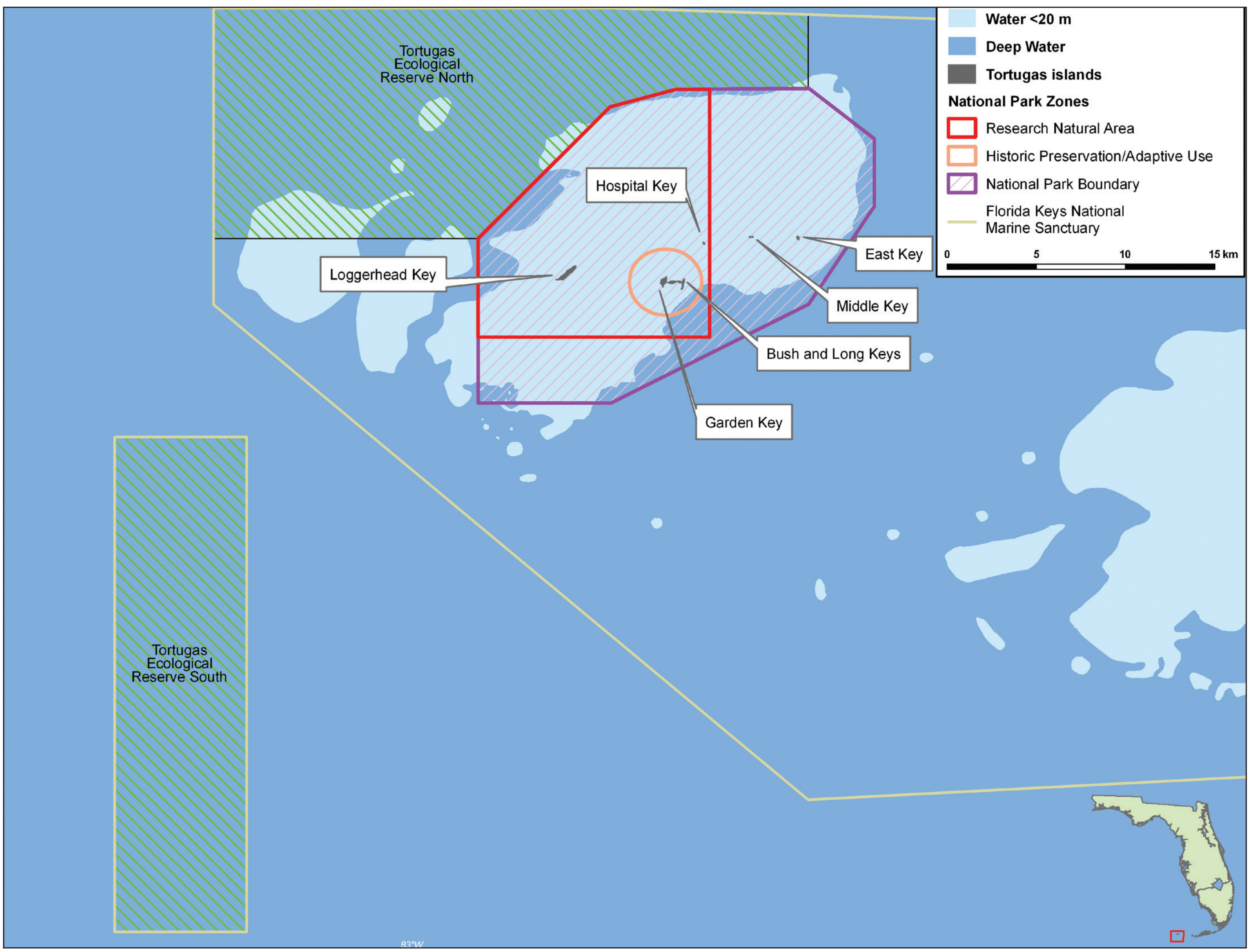

Figure 1.3. Islands and management zones of the Tortugas region, Florida Keys. Map: C.F.G. Jeffrey.

recreational activities within park boundaries. The state of Florida retained management rights to the seabed and associated resources, and in 2007 the state legislature collaborated with NPS to establish a 119-km^2 reserve area known as a Research Natural Area (RNA). The RNA is now closed to all recreational consumptive uses, but its regulations exclude an area 1.85 km in diameter around Garden Key Lighthouse as well as the developed areas on Loggerhead Key (Figure 1.3). Aquatic activities permitted within the RNA include boating, swimming, snorkeling, scuba diving, research and education but exclude anchoring and recreational fishing (SFNRC and FWC , 2007). Mooring buoys will be provided for snorkeling and scuba diving boat operations during the day. Additionally, RNA regulations prohibit manipulation of resources within its boundaries, except where needed to achieve restoration.

RATIONALE FOR IMPLEMENTATION OF THE TORTUGAS ECOLOGICAL RESERVE AND BOUNDARY SELECTION

A primary goal for implementation of the TER was the protection of natural resources (goods and services) that were both ecologically and economically important. Consequently the boundaries of the TER were chosen through a consensus-building process that involved governing agencies, several stakeholder meetings, a working group of experts, and period of public commentary and review. This consensus-based approach was used to increase the likelihood of future compliance and support by resource user groups through their participation in the process. Based on several criteria (Table 1.1), a preferred boundary option was selected for implementation from five proposed alternatives. The boundary selection process is described fully in the Final Supplemental Environmental Impact Statement / Final Supplemental Management Plan.

Table 1.1. Rationale used for selecting the boundaries of the TER. Source: Final Supplemental Environmental Impact Statement / Final Supplemental Management Plan pp. 70-71 (NOAA, 2000).

Management Focus	Rationale
Resource Protection	• Protects a range of contiguous habitats including shallow areas in the Dry Tortugas • Sufficient size to protect biological diversity and achieve fisheries sustainability criteria • Protects several known spawning sites and provides connectivity with other habitats • Includes Riley's Hump and a buffer area • Includes Sherwood Forest and its unique coral formations • Protects important habitat to the west and north of the Tortugas Bank • Protects deep water habitat and species such as Snowy Grouper (*Epinephelus niveatus*), Tilefish (*Malacanthus plumieri*), golden crab (*Chaceon fenneri*) and Red Snapper (*Lutjanus campechanus*)
Maximize enforceability	• Facilitates enforcement with simple boundaries
Maintain Socioeconomic Benefits and Livelihoods	• Leaves open significant fishery grounds for lobster and reef fish such as the southern half of the Tortugas Bank, which is an important fishing area in winter • Leaves open fishing areas for King Mackerel (*Scomberomorus cavalla*)
Provides Research and Monitoring Opportunities	• Includes long-term monitoring sites in the Dry Tortugas • Leaves open southern half of Tortugas Bank to be used as a reference site for gauging impacts of fishing on the ecosystem

EXPECTED OUTCOMES FROM IMPLEMENTATION OF THE TORTUGAS ECOLOGICAL RESERVE

The rationales listed in Table 1.1 imply that certain future outcomes were anticipated from the implementation of the TER. One postulate from marine reserve theory is that a reduction in fishing pressure ought to be accompanied by future measurable demographic changes such as increases in the abundance, average size, and spawning biomass of exploited fish populations (Murray et al., 1999). These demographic changes within a reserve then potentially would result in increased fishery benefits outside of the reserve through adult biomass and larval export (Bohnsack, 1998; Murray et al., 1999; Russ et al., 2004; Sponaugle et al., 2005). Through its establishment, the TER was expected to reduce mortality on exploited populations provided that there was high compliance by humans with its non-consumptives uses. Thus, at some future date after the establishment of the TER, a reversal from declining trends in exploited populations (e.g., fish and invertebrates), to increasing trends in those populations would occur in the Tortugas region, given that the TER reduced fishing pressure and mortality on natural populations.

Another postulate from marine reserve and economic theory is that short-term economic losses would occur and must be weighed against expected future benefits from reserve implementation (McClanahan and Mangi, 2000; Wilcox and Pomeroy, 2003; McClanahan et al., 2006). Although the location of TER boundary was chosen to minimize adverse socioeconomic effects, short-term economic losses to consumptive users still were hypothesized and expected. The TER closed 391 km^2 of marine waters to commercial and recreational fishing. Prior to TER implementation in 2001, about 105-110 commercial fishers operated 164 fishing vessels that targeted invertebrates (spiny lobster, *Panulirus argus*; shrimp and stone crabs) and reef fishes, Spanish (*Scomberomorus maculatus*) and King (*Scomberomorus cavalla*) Mackerels and sharks (Leeworthy and Wiley, 2000). Furthermore, about 85% of Tortugas' fishers were full-time operators that earned 100% of their income from fishing (Leeworthy and Wiley, 2000). Thus, termination of commercial and recreational fishing within the TER boundaries was expected to result in real short-term socioeconomic losses to operators in the region. Additionally, increased operational costs would be incurred because the displaced fishers had to relocate and find new fishing grounds.

PURPOSE OF THIS INTEGRATED ASSESSMENT

The TER Integrated Assessment had two broad goals: 1) to determine if expected demographic changes such as increases in abundance, average size and spawning potential of exploited populations occurred in the Tortugas region after reserve implementation; and 2) whether short-term economic losses occurred to fishers displaced by the reserve. To determine reserve effects on exploited populations, this project utilized a biogeographic approach in which information on the physical features (i.e., habitat) were used to determine the spatial distribution of selected fish populations within and outside the TER. Before-and-after reserve implementation comparisons of selected fish populations were then conducted to determine if demographic changes occurred in reef fish assemblages. These comparisons were done for the Tortugas region and also for a subset of available habitats within the Tortugas Ecological Reserve Study Area (TERSA; Figure 1.3). Social and economic impacts of the TER were determined through: 1) analyses of commercial landings and revenues from fishers, operating in the Tortugas region before and after TER implementation and 2) surveys of recreational tour guides. Analyses of the commercial landings and revenues excluded areas inside DRTO because commercial fishing has been prohibited within park boundaries since 1992.

Each chapter describes the goals and objectives of the research or monitoring study being presented and the outcomes (data collected and conclusions made) regarding the impacts of no-take reserves on fishery resources in Dry Tortugas. More specifically, Chapter 2 describes physical and oceanographic features of the Tortugas region. Physical and oceanographic variables are known to influence spatial patterns in the distribution of fish assemblages in the Tortugas region, and thus are important covariates for explaining observed demographic variability in reef fishes. Chapter 3 describes trends in reef fish metrics based on data obtained from synoptic visual censuses of reef fish assemblages inside and outside no-take reserves. Chapters 4 and 5 present studies that characterized benthic habitats and assessed reserve-impacts on reef fish populations at a sub-set of habitat-types (i.e. sand-reef interfaces) in the Tortugas region. Chapters 6 and 7 describe two approaches used to determine social and economic impacts of the TER on commercial fishers and recreational tour guides from the Tortugas. Chapter 8 describes a framework for conducting future Integrated Assessments based on lessons learned from this project. Finally, a synthesis of the important findings and conclusions of the Integrated Assessment, regarding the effects on no-take reserves on fishery resources in Dry Tortugas, are summarized in the Executive Summary found at the beginning of the report.

DEFINITION OF STUDY AREAS

For purposes of the analyses presented in this report, the study area encompasses a 3,503 km^2 (1,020 m^2) area referred to as the TERSA (Figure 1.4). This was the area selected by the FKNMS for analyzing five different alternatives, one of which became the TER. Socioeconomic information was collected and analyzed for recreational and commercial fisheries at a geographical resolution of 3.4 km^2 (one square mile) within the TERSA but excluding DRTO. Fishery–independent data on reef fish assemblages were collected and analyzed for the various management zones that exist within TERSA and DRTO (Figure 1.4). Hereafter, the use of the term “Tortugas region” refers to the combined area of the TERSA and the DRTO.

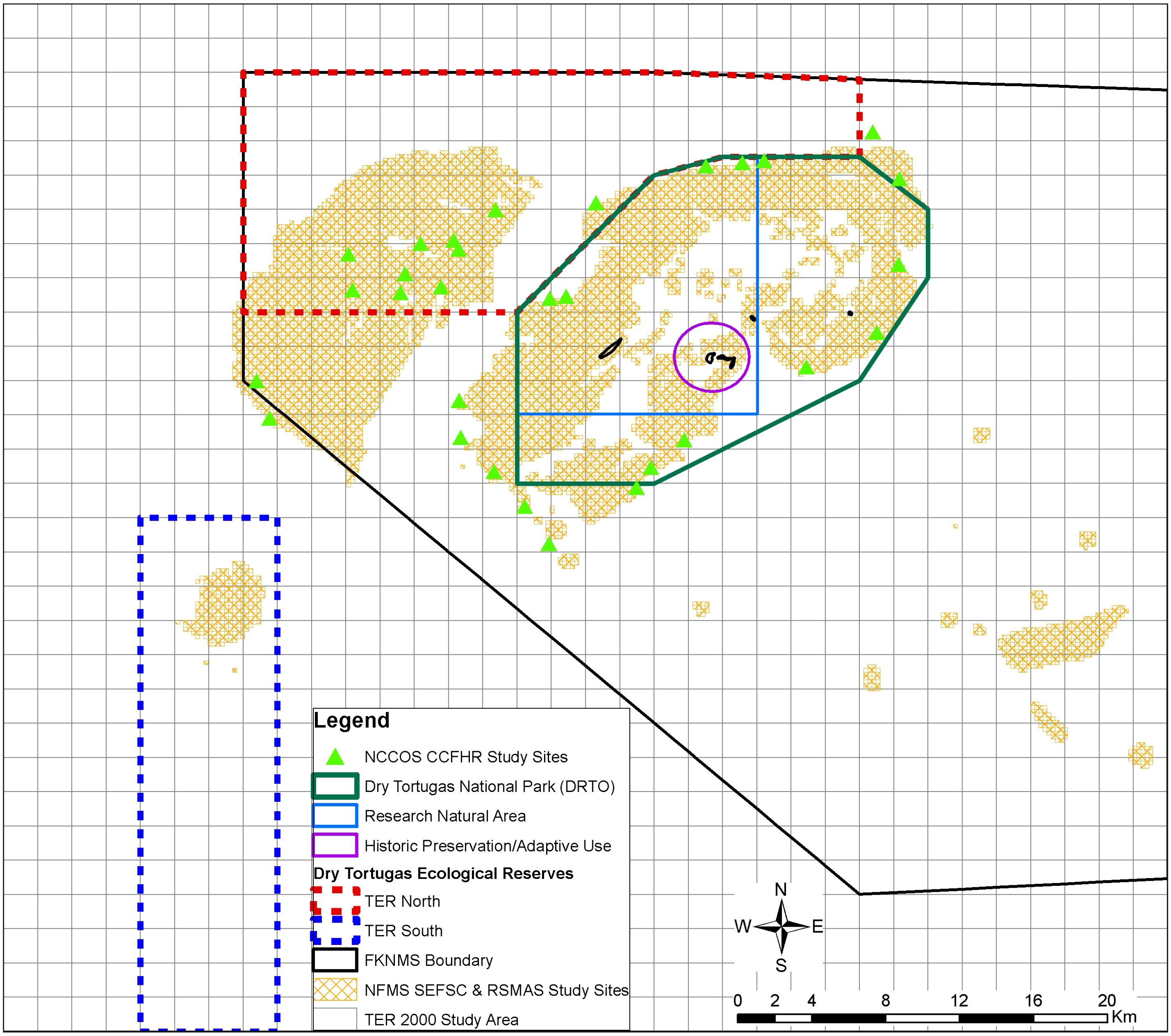

Figure 1.4. Tortugas Ecological Reserve Study Area (TERSA) showing management zones and locations of survey sites where fishery-independent monitoring data on fish assemblages were collected. Socioeconomic data on commercial and recreational fisheries were collected from the entire gridded area of the TERSA (excluding Dry Tortugas National Park, DRTO) at a spatial resolution of 3.4 km² (1 nm²).

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Chapter 2: Physical and Oceanographic Features of the Tortugas Ecological Reserve Study Area

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Steven G. Smith[3] and Varis Ransibrahmanakul[4]

INTRODUCTION AND BACKGROUND

Like everywhere else, coral reef fish assemblages in the Tortugas Ecological Reserve Study Area (TERSA) are known to be temporally and spatially variable. However, much of that variation correlates with environmental variables that are known to influence demographic and ecological processes. For example, the structure and quality of underlying habitats influence rates of recruitment, settlement, and the outcomes of competition and predation, all of which affect the size, spatial distribution and composition structure of reef fish population (Helfman, 1978; Sale et al., 1984; Parrish, 1989; Jones and Syms, 1998). Moreover, coral reef ecosystems comprise mosaics of habitat patches that themselves vary in their spatial and temporal distribution because of disturbance regimes that range in scale and intensity of their effects (Jackson, 1991; Hughes, 1994; Jones and Syms, 1998). Thus, quantifying patterns in the spatial distribution and configuration of habitats was crucial to explaining demographic patterns in coral reef fish assemblages and determining the effects of the Tortugas Ecological Reserve (TER) on resident fish assemblages (Ault et al., 1997; Ault et al., 2004; Ault et al., 2005a,b; Ault et al., 2006).

A major objective of the Tortugas integrated assessment was to synthesize existing data to develop the most up-to-date comprehensive digital benthic maps of the Tortugas region. Maps were needed to characterize benthic substrates and to identify environmental factors that could be used as covariates to explain spatial and temporal patterns in the occurrence and composition of fish assemblages (Ault et al., 2005a,b; Ault et al., 2006). Maps were also needed for developing habitat-based stratified sampling designs so that spatial and temporal changes in fish assemblage structure and composition caused by the TER could be differentiated from naturally occurring demographic variability (Burke et al., 2004; Ault et al., 2005a,b; Ault et al., 2006). Mapping for the Tortugas integrated assessment focused on two data types: benthic habitats and bathymetry.

INTEGRATION OF BATHYMETRIC AND BENTHIC HABITAT INFORMATION

Data from various mapping activities conducted by several organizations were compiled to generate benthic and bathymetry maps of the TERSA (Table 2.1). The two primary sources of benthic habitat data were (1) the 1998 polygon-based digital benthic habitat atlas of the Florida Keys National Marine Sanctuary (FKNMS) developed by the Florida Marine Research Institute (FMRI)[A], and (2) the 200 m x 200 m polygon grid benthic map developed by the University of Miami, Rosenstiel School of Marine and Atmospheric Science (UMRSMAS). In addition, *in situ* ground-truthing benthic habitat data from NOAA National Center for Coastal Ocean Science (NCCOS), Center for Coastal Fisheries and Habitat Research (CCFHR) were used to fill gaps and validate the final map (Figure 2.1). The extent of the FMRI-NOAA (1998) map was limited to the soft-sediment, coral reef and hard-bottom habitats within the shallow-waters (<20 m depth) of the Dry Tortugas National Park (DRTO) and did not include deeper areas such as the Tortugas Bank, which is now partially contained within no-take marine protected area boundaries. The integrated map produced by this project has expanded the mapped areas of the Tortugas region to include Riley's Hump, Tortugas Bank, and other areas less than 33 m deep between the Marquesas and DRTO (Figure 2.1). The total area mapped by UMRSMAS is 35,560 ha compared with 10,033 ha mapped by FMRI and NOAA in 1998.

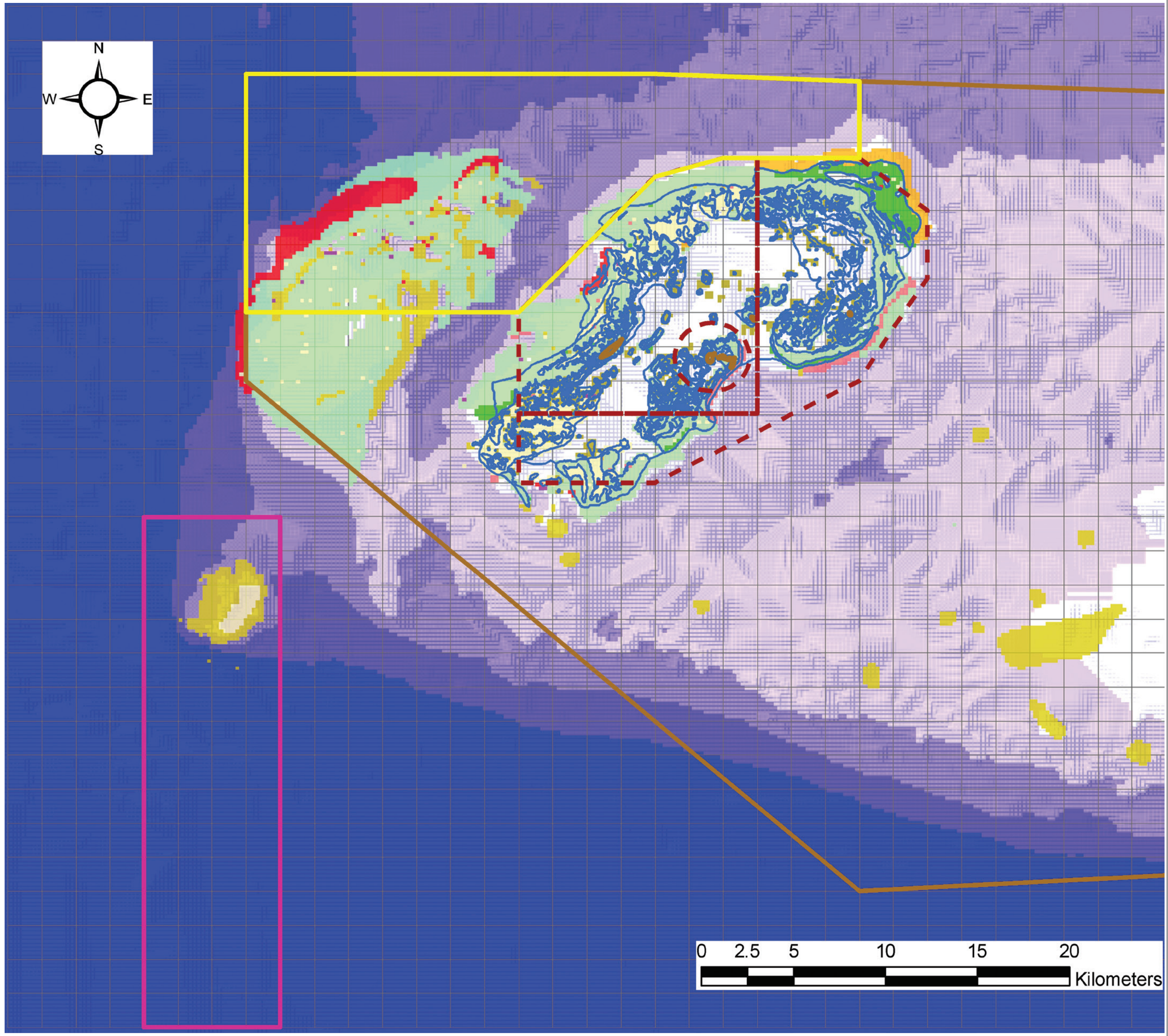
1. NOAA/NOS/NCCOS/CCMA Biogeography Branch
2. CSS-Dynamac, Fairfax, VA
3. University of Miami, Rosenstiel School for Marine and Atmospheric Science
4. NOAA/NOS/NCCOS/CCMA Coastal Oceanographic Assessments, Status and Trends Branch

A. The Florida Marine Research Institute was renamed the Florida Fish and Wildlife Research Institute (FWRI) on July 1, 2004.

Table 2.1. Sources of bathymetric data used in the Tortugas Integrated Assessment.

Data Set	Source	Description	Spatial Coverage	Variables
NOAA/NOS Hydrographic Surveys	NOAA/National Geophysical Data Center, Boulder, Colorado. http://www.ngdc.noaa.gov/mgg/fliers/03mgg03.html	Depth soundings, NOS Hydrographic Survey Data, Version 4.0 Vol. 1&2.	Several discrete areas of the Tortugas region.	Latitude, Longitude, Depth.
Marine Trackline Geophysics	National Geophysical Data Center, Boulder, Colorado. http://www.ngdc.noaa.gov/mgg/fliers/03mgg02.html	Depth soundings, Marine Trackline Geophysics, Version 4.0 Vol.1,2,&3.	Tracklines in the Tortugas region.	Latitude, Longitude, Depth.
Two-Minute Gridded Global Relief Data	http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html	http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html	Global; gridded in 2 minute resolution.	depth (m) in gridded format.
NMFS Acoustic Survey	Chris Glendhill, NMFS Pascagoula	Hydroacoustic survey of bathymetry.	Widely spaced acoustic tracklines in discrete areas of the Tortugas region.	Latitude, Longitude, Depth.
NOAA/NOS Hydrographic Surveys, multibeam 2000	NOAA Silver Spring, MD. http://www.ngdc.noaa.gov/ngdc.html	Depth soundings from multi-beam sonar survey conducted by NOAA/NOS	About 4 km^2 around Sherwood Forest area of the Tortugas region.	Latitude, Longitude, Depth.
NOAA/NOS Hydrographic Surveys, side-scan 1998	NOAA Silver Spring, MD. http://www.ngdc.noaa.gov/ngdc.html	Bathymetric and bottom substrate data from side-scan surveys conducted by NOAA/NOS hydrographic teams (1998).	Several discrete areas of the Tortugas region.	Latitude, Longitude, Depth, Side-scan images.
NOAA/NOS Hydrographic Surveys, side-scan 2000	NOAA Silver Spring, MD. http://www.ngdc.noaa.gov/ngdc.html	Bathymetric and bottom substrate data from side-scan surveys conducted by NOAA/NOS hydrographic teams (2000).	Several discrete areas of the Tortugas region	Latitude, Longitude, Depth, Side-scan images.
Multibeam data NOAA ship Whiting (2001-2002)	NOS, Norfolk, Va.	Depth soundings from multi-beam sonar survey conducted by NOAA/NOS Hydrographic Teams.	Riley's Hump, south Tortugas Bank, the slope of north Tortugas Bank	Latitude, Longitude, Depth.
Mulitbeam data NOAA ship Nancy Foster (2004)	NOAA CCFHR, Beaufort, NC. http://surveys.ngdc.noaa.gov/mgg/NOS/coast/H10001-H12000/H11340/DR/H11340.pdf	Depth soundings from multi-beam sonar survey conducted by NOAA Center for Coastal Fisheries and Habitat Research (CCFHR).	16 study sites (about 1 km x 4 km each) from TD bank to the park.	Latitude, Longitude, Depth.
United States Geological Survey (USGS) Center for Coastal and Watershed Studies, 2006, Dry Tortugas National Park EAARL Submarine/Subaerial/Merged Topography	Brock, J.C., Wright, C.W., Patterson, M., Nayegandhi, A., Patterson, J (2006). USGS-NASA_NPS EAARL topography – Dry Tortugas National Park: U.S. Geological Survey Open-File Report 2006-1244. http://pubs.usgs.gov/of/2006/1244/	Lidar-derived submarine topography map produced as a collaborative effort between the USGS Coastal and Marine Geology Program, NPS South Florida/Caribbean Network Inventory and Monitoring Program, and NASA Wallops Flight Facility.	Most shallow water (less than 15 m) of the Dry Tortugas National Park (DRTO).	Latitude, Longitude, Depth.

1. SANDS is a USGS developed, high precision bathymetric system which integrates depth soundings, boat motion, and GPS positioning needed for nearshore bathymetric mapping. Data acquisition occurred between 1995 and 1999 on a shallow 22 ft. shallow draft boat. Processed data points are in X, Y, Z format and relative to the North American Datum of 1988 (NAVD88). Vertical control was derived from GPS data processed with Jet propulsion Laboratory GIPSY software. Horizontal and vertical accuracies are within ± 4 cm and ± 8 cm respectively.



UM-RSMAS / NURC Habitat	Area (ha)
Low-relief HB	19,995
Low-relief SG	1,184
Patchy HB in sand	3,753
High-relief SG	508
Pinnacle reef	68
Reef terrace	1,648
Medium reef	776
Rocky outcrops	4,816
Patch reef	2,813
Total	**35,560**
FMRI-NOAA Habitat	
Hardbottom with seagrass	16
Patch reef	868
Platform margin reef	9,149
Total	**10,033**

Figure 2.1. Coral reef and hard-bottom areas in the Tortugas Ecological Reserve Study Area (TERSA) that was mapped by University of Miami, Rosenstiel School of Marine Science (UMRSMAS), NOAA Southeast Fisheries Science Center (SEFSC), and NOAA National Undersea Research Center (NURC). Benthic data layers were updated in 2006. Polygons (blue lines) from Florida Marine Research Institute (FMRI)-NOAA benthic map are also included to show the additional areas characterized by the new map. The nine habitat classes are defined in Table 2.3.

The two most extensive bathymetric data sets for the TERSA were (1) multi-beam soundings collected in 2004 by CCFHR, and (2) the airborne light detection and ranging (LIDAR) soundings collected by U.S. Geological Survey (USGS), National Aeronautics and Space Administration (NASA) and National Park Service (NPS). These data sets were supplemented with additional data from sources listed in Table 2.1 to generate bathymetric maps of the TERSA at resolutions of 10 m (Figure 2.2).[B] Additionally, rugosity maps that describe the complexity of the submarine topography were derived by performing the second derivative on the multi-beam and LIDAR bathymetry data (Figure 2.3). Below is a review of the various mapping products used to develop integrated benthic and bathymetric maps of the TERSA. Metadata for the datasets are provided in Appendix I. Following is a description of sources and types of physical and oceanographic data that were synthesized for the Tortugas Integrated Assessment project.

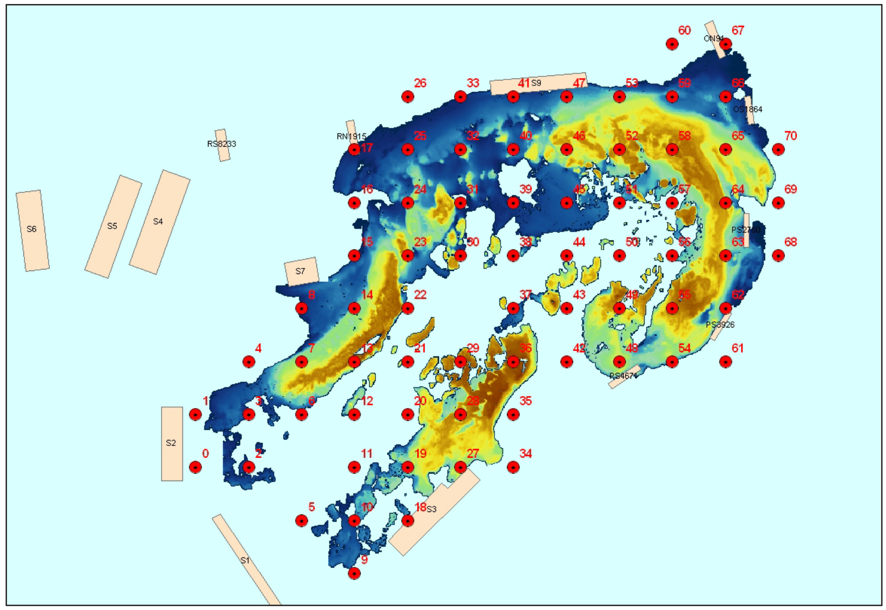


Figure 2.2. Integration of airborne light detection and ranging (LIDAR; continuous surface of blues and yellows) and multi-beam (tan polygons) bathymetry data for the Tortugas region. LIDAR data for the Dry Tortugas National Park (DRTO) were collected by U.S. Geological Survey (USGS), National Aeronautics and Space Administration (NASA) and National Park Service (NPS). Multibeam data for the TERSA and DRTO were collected by NOAA National Center for Coastal Ocean Science (NCCOS), Center for Coastal Fisheries and Habitat Research (CCFHR). Resolution of the integrated data set is 10 m. Source: J. Luo, University of Miami, Rosenstiel School of Marine and Atmospheric Science (UMRSMAS).

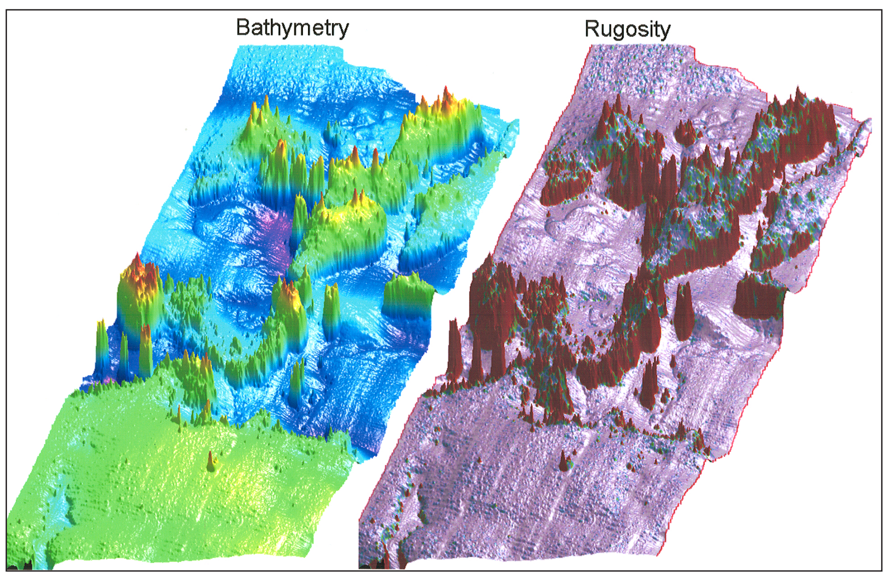


Figure 2.3. Rugosity (right) derived from bathymetry data (left) showing the degree of hard bottom complexity in the Tortugas region. Source: J. Luo, UMRSMAS.

B. Bathymetric maps for the Tortugas region were generated at a resolution of 0.0001 degree, which is approximately 10 m. Maps of south Florida region were generated at 0.002 degree, which is equivalent to 200 m.

Florida Marine Research Institute and NOAA Mapping Activities and Products

In 1998, a six year collaborative effort between NOAA and FMRI culminated in the production of an atlas and a CD-ROM containing data on the types, location, coverage and depths of benthic habitats within the FKNMS (FMRI and NOAA, 1998). Benthic habitats were identified from 450 natural color aerial photographs of the Florida Keys region acquired by remote sensing from December 1991 through March 1992. The photographs were at a scale of 1:48,000 and covered an area of approximately 160 km^2, or 3% of the FKNMS. A hierarchical classification scheme was used to interpret and delineate the benthic communities seen in the aerial photographs. The hierarchical classification consisted of six major habitat categories and 12 subcategories. The minimum habitat area delineated was 0.05 km^2; however, identifiable patch reefs <0.5 ha were delineated also because of their ecological significance as critical habitat (FMRI and NOAA, 1998). Figure 2.4 shows the benthic habitat map developed from the 1991-1992 imagery.

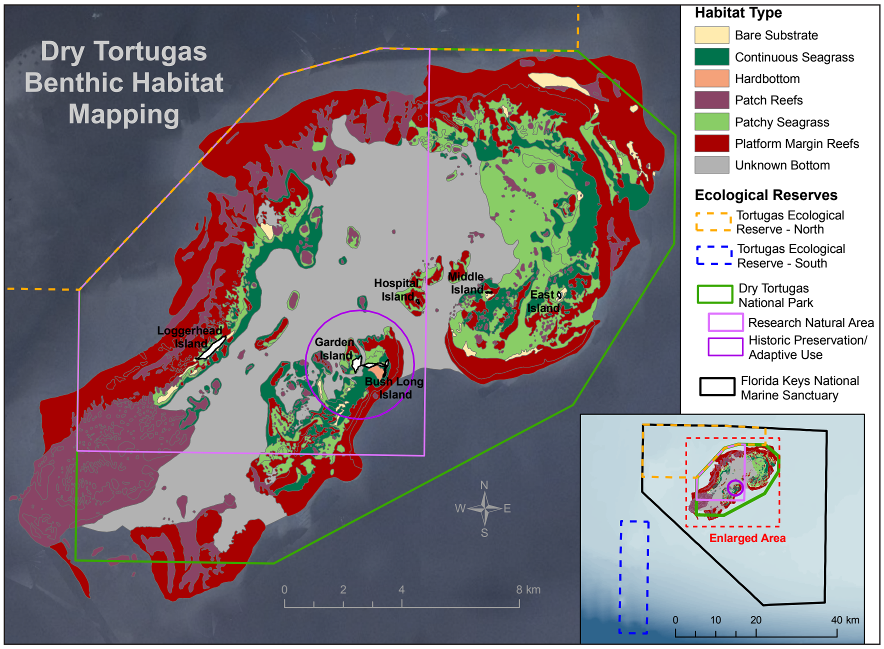


Figure 2.4. Benthic habitats of the DRTO. Source: FRMI and NOAA, 1998.

In 2001, NOAA's Coastal Services Center, Dade County Florida, and the Florida Fish and Wildlife Research Institute (formerly FMRI) released an updated version of the FKNMS and Dry Tortugas benthic data set, which was edited to correct attribute errors found in the benthic map. Benthic maps of Biscayne and Florida Bays were also included in the updated version. Table 2.2 shows a comparison of the percent area characterized in the Tortugas region by the 1998 map compared with the corrected map released in 2001. Subsequent to the FMRI-NOAA mapping effort, additional mapping in the TERSA was conducted with a variety of remote-sensing technologies by UMRSMAS, and USGS, NPS and NASA. Following are brief descriptions of these mapping activities and products for the TERSA.

Table 2.2. Frequency of occurrence and percent area of benthic habitats in the DRTO Source: FMRI and NOAA, 1998.

Habitat Category	Area		% Area	
	FMRI (1998)	FMRI (2001)	FMRI (1998)	FMRI (2001)
Patch Reefs	710	3,549	3.5	16.8
Platform Margin Reefs	8,750	6,468	42.6	30.7
Seagrass	4,440	4,438	21.6	21.0
Hardbottom	20	16	0.1	0.1
Bare Substrate	210	210	1.0	1.0
Unknown	6,400	6,405	31.2	30.4
Total	**20,530**	**21,086**	**100**	**100**

University of Miami Mapping Activities and Products

Characterization of benthic habitats in the TERSA has also been a major component of a fisheries-independent and benthic habitat monitoring program conducted by UMRSMAS, National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center (SEFSC), and NOAA National Undersea Research Center (NURC) at the University of North Carolina at Wilmington. Implemented prior to the establishment of no-take reserves in the Florida Keys, the primary objectives of this monitoring program included the development of baseline estimates for detecting long-term demographic changes in populations of reef fishes and other coral reef organisms as well as understanding marine reserve design and efficacy in rebuilding depleted fishery resources (Schmidt et al., 1999; Ault et al., 2002; Franklin et al., 2003). However, achievement of these objectives required detailed information on habitats (e.g., bathymetry, substrate types and benthic composition) for the development of precise estimates for abundance, biomass, size structure and recruitment of reef fish populations in the TERSA.

To fill this data gap on benthic habitats, UMRSMAS integrated data from hydrographic surveys, single-beam side-scan sonar, *in situ* surveys, and exiting benthic habitat thematic layers to develop more detailed digital benthic maps of coral reef and hard-bottom habitats for the Tortugas region. A 200 x 200 m polygon grid was created for the Tortugas region from (1) a bathymetric grid, (2) a mosaic of bottom topography developed from single-beam side-scan sonar, and (3) thematic data layers from the FRMI-NOAA-1998 benthic habitat map (Franklin et al. 2003). *In situ* surveys were then conducted to assign habitat categories from a classification scheme to each polygon grid. The habitat classification scheme used by UMRSMAS was based on habitat relief and patchiness and described nine distinct hard-bottom and coral reef habitats encountered from 1–33 m depth (Table 2.3). An added advantage of the 200 x 200 m grid is that each grid cell can be updated and correctly attributed as new or additional information on habitats become available. Specific details about the mapping methodology used by UMRSMAS are given in Ault et al. (2002) and Franklin et al. (2003).

Table 2.3. Characteristics of nine coral reef-and hard-bottom benthic habitat types classified in the Tortugas Ecological Reserve Study Region (TERSA). Habitat types with asterisks only occur within the DRTO. Source: Franklin et al., 2003.

Habitat Type	Characteristics
Patch hard-bottom in sand	Sand plains with patches of hard-bottom
	Low vertical relief (<0.5 m) and complexity
Low-relief hard-bottom	Contiguous hard-bottom substrate
	Low structural complexity and relief
	Usually dominated by gorgonians
Rocky Outcrop	Hard-bottom aggregations bounded by sand
	Moderate vertical relief (0.5-2.0 m)
Pinnacle reef	High-complexity patches rising to 15 m depth
	Surrounded by sand plains
Reef terrace	High-relief (>2 m), contiguous reef habitat
	Abundant and large mushroom and platy coral
	Primarily located on western sides of banks
Patch reef*	Aggregate or clusters of dome-shaped reefs
	Interspersed with sand
	Moderate vertical relief and substrate complexity
	Similar to patch reefs in Florida Keys
Medium-profile reef*	Contiguous reef substrate
	Moderate vertical relief and complexity
Low-relief spur and groove*	Low-profile coralline spurs separated by sand grooves
	Broad spurs up to 5 m wide with low vertical relief
High-relief spur and groove*	High-profile coralline spurs separated by sand grooves
	High vertical relief (>2 m) and complexity
	Diverse assemblage of reef benthos

National Centers for Coastal Ocean Science Center for Coastal Fisheries and Habitat Research Mapping Activities and Products

Scientists from the CCFHR within NOAA have conducted targeted "coarse-scale" mapping of benthic habitats at 30 randomly selected sand-reef interfaces in the Tortugas region (Fonseca et al., 2006). Coarse-scale mapping was done with an instrument called the MiniBAT®, side-scan SONAR, multi-beam SONAR, and aerial and satellite imagery. The MiniBAT® housed a downward-facing camera linked to a real-time differential Global Positioning System (DGPS) and was used to videotape the seafloor at 5 to 8 m resolution along selected depth-contours (Figure 2.5).[D] CCFHR conducted additional mapping of their sites with side-scan sonar in 2002 and 2003 (Figure 2.6). CCFHR also acquired aerial photography in 2001 for the DRTO, and purchased IKONOS and

D. A detailed description of the MiniBAT's® instrumentation and configuration is given in Fonseca et al. (2006).

QuickBird satellite imagery in 2003 for the area around Fort Jefferson. CCHFR visited over 300 randomly selected sites in the Tortugas to collect data to ground-truth the imagery, and those data were used to update the NOAA-FMRI benthic map developed from aerial photography taken in 1991 (Fonseca et al., 2006). In 2004, high-resolution hydrographic surveys of the 30 permanent stations were conducted with a Simrad EM3000 multibeam echo-sounder. The sonar system produced a swath of sonar approximately 3.5 to 4 times the water depth and collected approximately 400 soundings per m^2. Specific details on CCHFR mapping methods are given in Fonseca et al. (2006) and Appendix I (multibeam metadata).

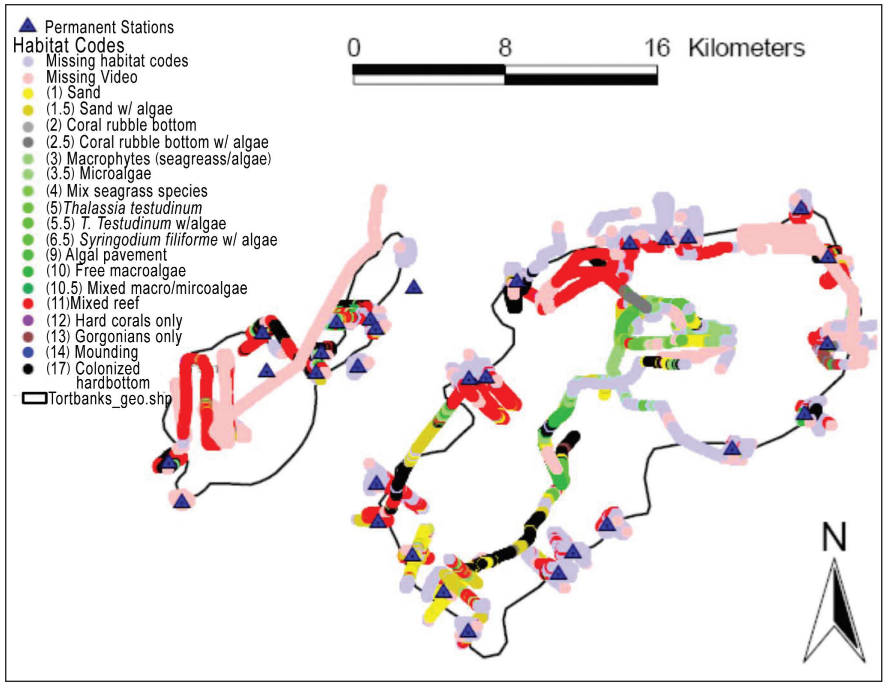


Figure 2.5. Map of track lines with habitat classification from 2000-2004 MiniBAT-towed video transects. Source: Fonseca et al., 2006.

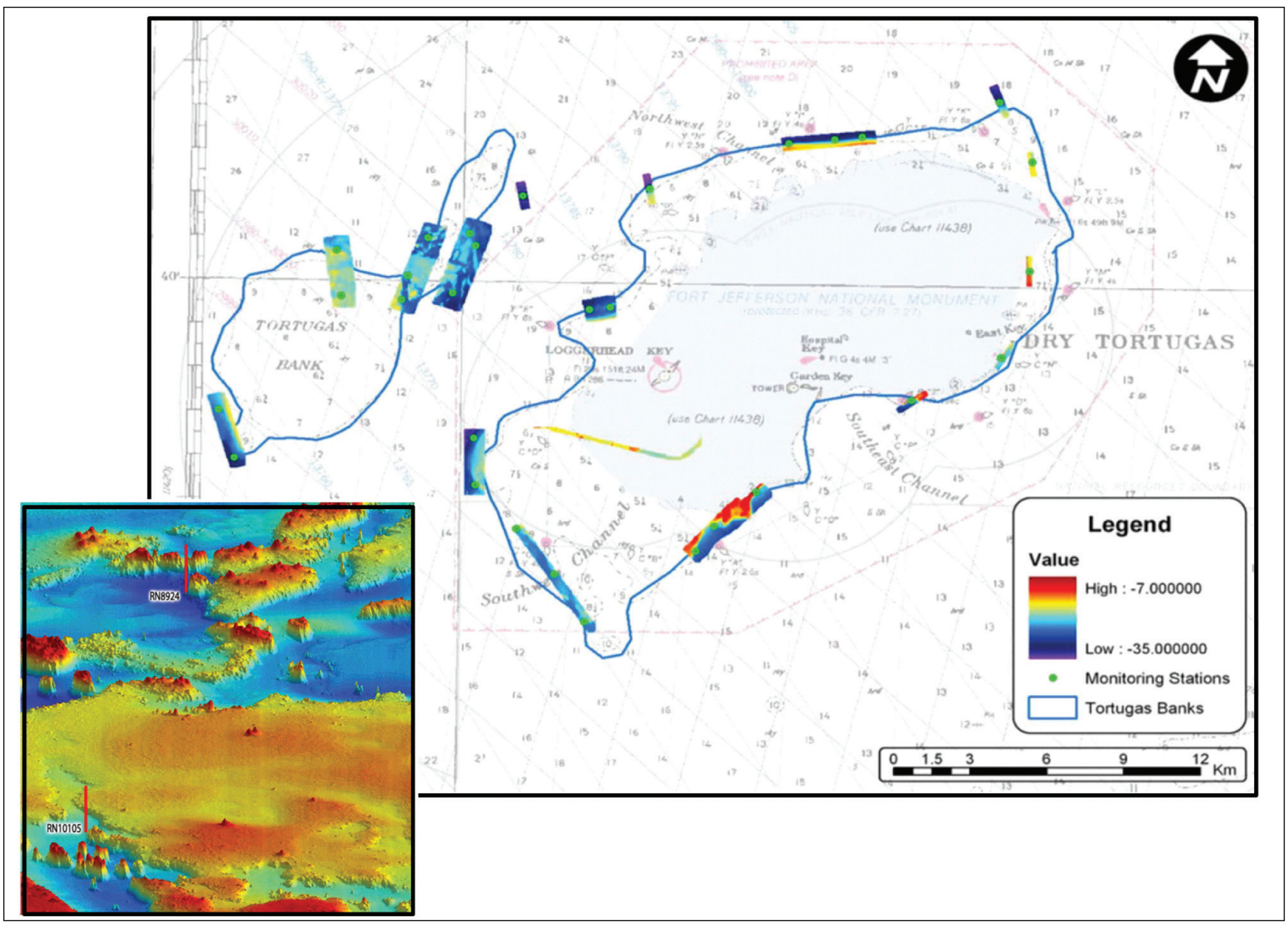


Figure 2.6. Simrad EM3000 bathymetric coverage over the 30 permanent stations. High resolution image encompassing sites RN10105 and RN8924 (inset).

During years 2001 through 2005, CCFHR scientists also conducted detailed “fine-scale” mapping to characterize benthic composition at sub-centimeter resolution at each of the 30 selected sand-reef interface sites in the Tortugas region. Divers used a digital video or still camera system to conduct video or photo transects of benthic habitat and to record the substrate along the length of each transect. Video collection techniques were based on those used by the Coral Reef Evaluation and Monitoring Project at FWRI (Kohler et al., 2006; Callahan et al., 2007; FWRI, 2009). A dive data recorder (Sensus Pro, ReefNet Inc.) affixed to the camera housing recorded a continuous depth profile for the duration of the video transect. The methods used to map benthic habitat are described in detail in Chapter 4 of this report, Fonseca et al. (2006) and Appendix I.

Aerial Photography and Satellite Imagery

To date, two image processing procedures have been conducted on the IKONOS and QuickBird imagery acquired by CCFHR: depth determination and habitat classification. Since the late 1970s scientists have been using air photos and a wide variety of digital imagery to estimate water depth. Although not as accurate as sonar techniques, imagery can provide relatively accurate estimates of depth. These techniques can provide valuable information, particularly in remote areas where surveys based on sonar techniques are rare or nonexistent. A ratio method of depth determination developed by Stumpf et al. (2003) was applied to both the IKONOS and QuickBird images and compared to over 28,400 DGPS referenced depth soundings recorded during a ground-truthing mission in December 2003. Error for both image sources increased with depth. For IKONOS, root mean square error (RMSE) gradually increased up to 2.1 at a depth of 16 m; after 16 m, RMSE rose rapidly, mostly due to turbidity. QuickBird did not perform as well due to an unreported problem with the green band.

The algorithms of Stumpf et al. (2003) rely on a ratio of the blue and green bands to estimate depths deeper than approximately 4 m and a ratio of the blue and red bands to estimate depths between 0 and 4 m. Due to a calibration error in the green band, the blue/green ratio was affected, making depth estimates deeper than 4 m unreliable. To date we have found no mention of this problem in the literature. Although poor calibration of the green band causes no problems for visual interpretation, QuickBird imagery may be inadequate for users that rely on a normal blue/green relationship in studies concerning aquatic environments. Habitat classification of IKONOS and QuickBird images, while not complete, has shown tendencies similar to other studies of coral, seagrass and algae environments (Mumby et al., 1997; 1998).

Coral and seagrass habitats as deep as 18 m can be easily visualized in the imagery. However, comparison of individual bands to the 28,400 depth soundings described above indicates that the red band only aids discrimination of bottom habitats down to 3 or 4 m. With the infrared bands of both satellites essentially useless for submerged habitat discrimination, this only leaves the blue and green bands that are useful below 4 m. With only two relatively broad bands of any use below 4 m, the ability to distinguish between seagrass, algae and coral communities based on spectra alone is limited. Initial results using Feature Analyst® automated feature extraction software (Visual Learning Systems, Inc.), an object oriented image processing system that easily allows inclusion of texture and depth to the processing stream, has aided accuracies below 4 m.

Simrad EM3000 Multibeam Echosounder

The Simrad EM3000 survey totaled approximately 500 line kilometers of multibeam data that comprised approximately 72.5 km^2 within the 30 permanent stations. Geodynamics has provided a final report containing the edited survey data with GIS compatible files depicting multibeam imagery and high-resolution 3-D images of the areas encompassing the 30 stations (Figure 2.6). Additionally, a multi-scale assessment of the multibeam data is being done. At each station, data is clipped at three extents (30 x 30, 100 x 100 and 300 x 300 m) with four resolutions per extent (0.5, 1, 3 and 10 m). Using semivariance analysis (GS+ Version 7.0, Gamma Design Software), CCFHR is currently examining the data to determine the scale at which significant changes in habitat and biological data could be detected.

U.S. Geological Survey Mapping Activities and Products

During July to August 2004, the USGS Coastal and Marine Geology Program, NPS South Florida/Caribbean Network (SFCN) Inventory and Monitoring Program, and the NASA Wallops Flight Facility used LIDAR technology to develop bathymetric maps of the TERSA. LIDAR is a remote sensing technique that uses laser light to detect, range, or identify remote objects based on light reflected by the object or emitted through it subsequent fluorescence (Brock et al., 2006). An aircraft-mounted pulsed-laser instrument collected soundings at a horizontal resolution of 1 m^2 and vertical resolution of 15 cm to measure the submerged topography of the Dry Tortugas reef tract up to a depth of 15 m. Specialized processing algorithms developed by USGS and NASA were used to convert the raw LIDAR data into geotiffs (x, y, z) to depict bathymetric features (Figure 2.7). Detailed information about these data can be found at http://pubs.usgs.gov/of/2006/1244/start.htm.

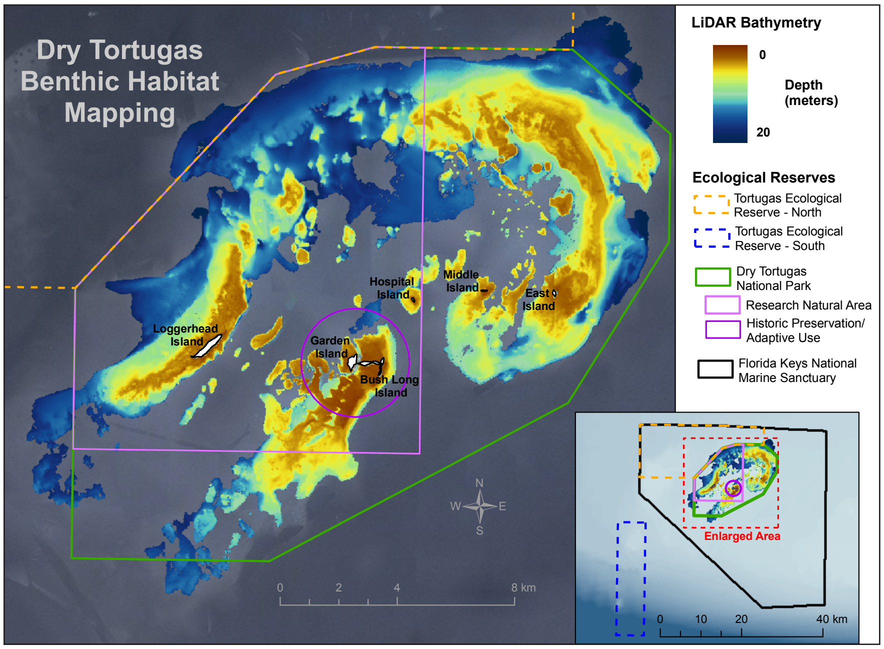


Figure 2.7. Map of the DRTO showing bathymetry derived from LIDAR soundings. Data were collected in 2004 by the USGS Coastal and Marine Geology Program, NPS South Florida/Caribbean Network (SFCN) Inventory and Monitoring Program and the NASA Wallops Flight Facility.

SYNTHESIS AND SUMMARY OF OCEANOGRAPHIC FEATURES IN THE TORTUGAS ECOLOGICAL RESERVE STUDY AREA

Maps of remotely-sensed data from satellites provide important climatological characterizations that may help explain long-term temporal (>10 yr) and broad-scale (tens of kilometers) distribution patterns of marine organisms. Circulatory patterns confirmed by remote-sensing and drifter buoy studies indicate that the Tortugas region can out-source larvae of fishes and other invertebrates eastward along the Florida Keys to the West Florida Shelf and Florida East Coast as well as receive propagules from those areas (Lee and Williams, 1999; Yeung and Lee, 2002; Burke et al., 2004; Sponaugle et al., 2005). To this end, data on oceanographic features (ocean currents, sea surface temperature or SST, and ocean color) were also assessed as part of the Tortugas integrated assessment, and were used in subsequent chapters to provide oceanographic context for assessing reserve effects on fish populations.

Data on current flow and SST for the TERSA were derived from the Hybrid Coordinate Ocean Model (HYCOM; http://www.hycom.org). HYCOM is a grid-based general circulation model that simulates existing and predicts future three dimensional (x, y, z) oceanographic and physical properties of oceanic waters (Bleck, 2002; Wallcraft et al., 2009). The vertical (z) coordinates of grid points are the depths of seawater parcels that have similar densities, and thus form continuous isopycnal surfaces or layers. Within the model, each coordinate surface is assigned a reference isopycnal layer. HYCOM then continually checks whether or not grid points lie on their reference isopycnal layer. If not, the model tries to move them vertically toward the latter, however, migration of grid points are prevented if it would lead to excessive crowding of coordinate surfaces. Thus, in shallow water, vertical grid points are geometrically constrained to remain at fixed depth while being allowed to join and follow their reference isopycnals over the adjacent deep ocean. The spatial resolution of the data is about 7 km with about 24 vertical layers representing different seawater density surfaces.

Nested within HYCOM is the South Florida Regional Model (SoFLA-HYCOM), which was developed to accurately simulate interactions between the shallow-water dynamics of the Florida Bay / Florida Keys and larger-scale flows of adjacent oceans (Kourafalou et al., 2005). The SoFLA-HYCOM provides more realistic representations of oceanographic conditions, circulation and biochemical exchange among distinct water bodies in South Florida, while maintaining connectivity with adjacent seas (Kourafalou et al., 2005). The SoFLA-HYCOM contains 20 surface layers of seawater density and a horizontal resolution of 3-3.5 km (Kourafalou et al., 2005). The spatial extent covered by the SoFLA-HYCOM includes Florida Bay, Florida Keys and Dry Tortugas (Figure 2.8). Specific outputs obtained for this integrated assessment include surface current vectors plotted over South Florida regional bathymetry for September 20, 2006 (Figure 2.9) and SST obtained for February 1, 2006 (Figure 2.10). Up-to-date outputs from SoFLA-HYCOM are available at http://hycom.org/regional, and detailed information on the oceanography of the South Florida including the TERSA is available online at http://www.hycom.org/attachments/086_Kourafalou_171_USGODAE1.pdf.

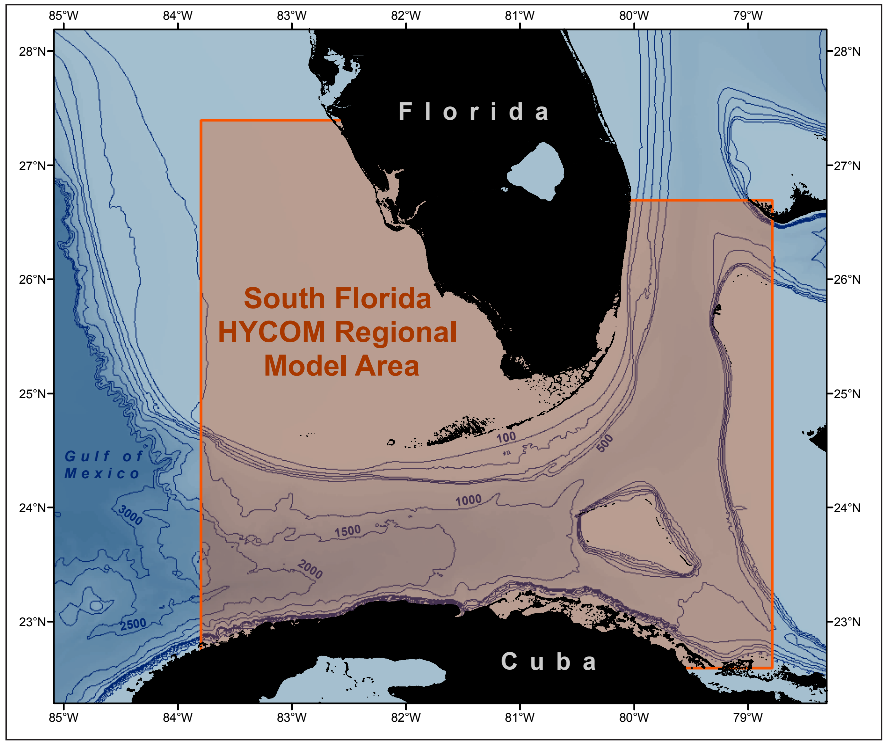


Figure 2.8. Spatial extent of the South Florida Hybrid Coordinate Ocean Model (SoFLA-HYCOM), which provided surface current vectors and sea surface temperature for the TERSA. Source: Kourafalou et al., 2005.

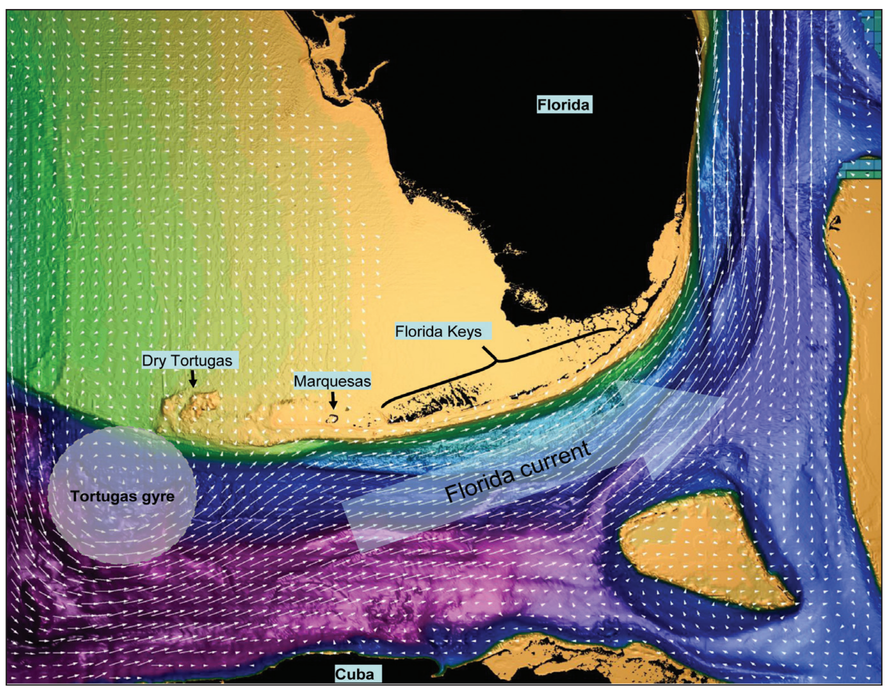


Figure 2.9. Surface current vectors derived from HYCOM model plotted over bathymetry for Florida reef tract. HYCOM model output is for September 20, 2006. Source: http://www.hycom.org.

SST images for the TERSA from 1985-2005 were acquired from NOAA's Coral Reef Temperature Anomaly Database (CoRTAD). CoRTAD is a collection of SST and related thermal stress metrics developed specifically for coral reef ecosystem applications, but it is relevant to other ecosystems as well. CoRTAD SST was derived from the near infrared bands of Advanced Very High Resolution Radiometer sensor (Halpern et al., 2008). CoRTAD contains global SST data at approximately 4 km resolution on a weekly time scale from 1985 through 2005. CoRTAD SST were binned into 0.5°C increments and plotted against the number of weeks to identify the occurrence and duration of extreme temperature events in the TERSA (Figure 2.11). The CoRTAD data show that the median temperature across all years was 24.5 °C, with a low of 20.5 °C occurring in 2003, and the highest temperature (27.5°C) occurring during several years: 1987, 1989, 1992, 1996, 1997, 2000 and 2002 (Figure 2.11).

Data on ocean color were obtained from the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) project that provides global ocean bio-optical properties to the earth science community. Subtle changes in ocean color signify various types and quantities of marine phytoplankton, the knowledge of which has both scientific and practical applications. The SeaWiFS Project develops and operates a research data system that processes, calibrates, validates, archives and distributes data received from an earth-orbiting color sensor. Chlorophyll-a concentration maps were downloaded from SeaWiFS to show changes in productivity of the region. The maps were obtained for November 2004, February 2004, May 2004 and July 2004 (Figure 2.12).

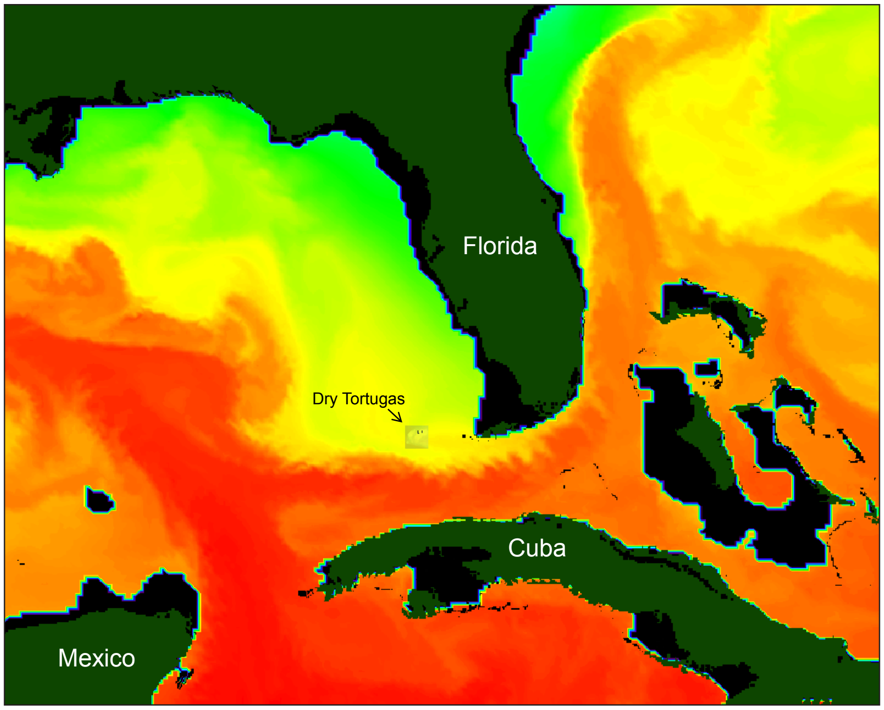


Figure 2.10. Sea surface temperature for the Florida derived from SoFLA-HYCOM model. SoFLA-HYCOM model output is for September 20, 2006. Source: http://www.hycom.org.

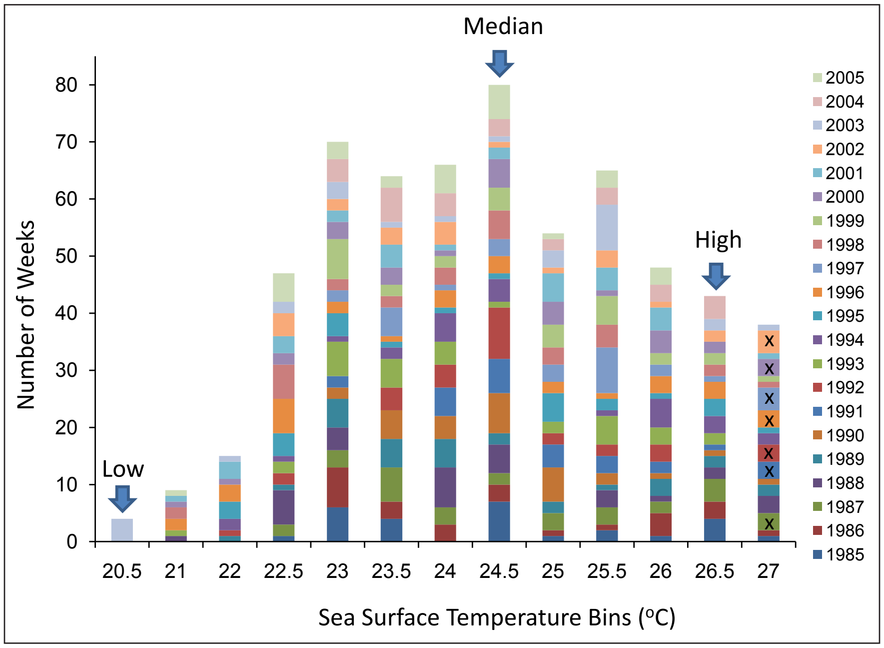


Figure 2.11. Histogram of weekly sea surface temperature (SST) from Dry Tortugas, FL. An "X" denotes any year when the TERSA experienced unusually long duration of SST>27°C: 2002, 2000, 1997, 1996, 1992, 1989 and 1987. Source: http://www.nodc.noaa.gov/SatelliteData/Cortad/; figure: V. Ransibrahmanakul, NCCOS Coastal Oceanographic Assessments, Status and Trends (COAST) Branch.

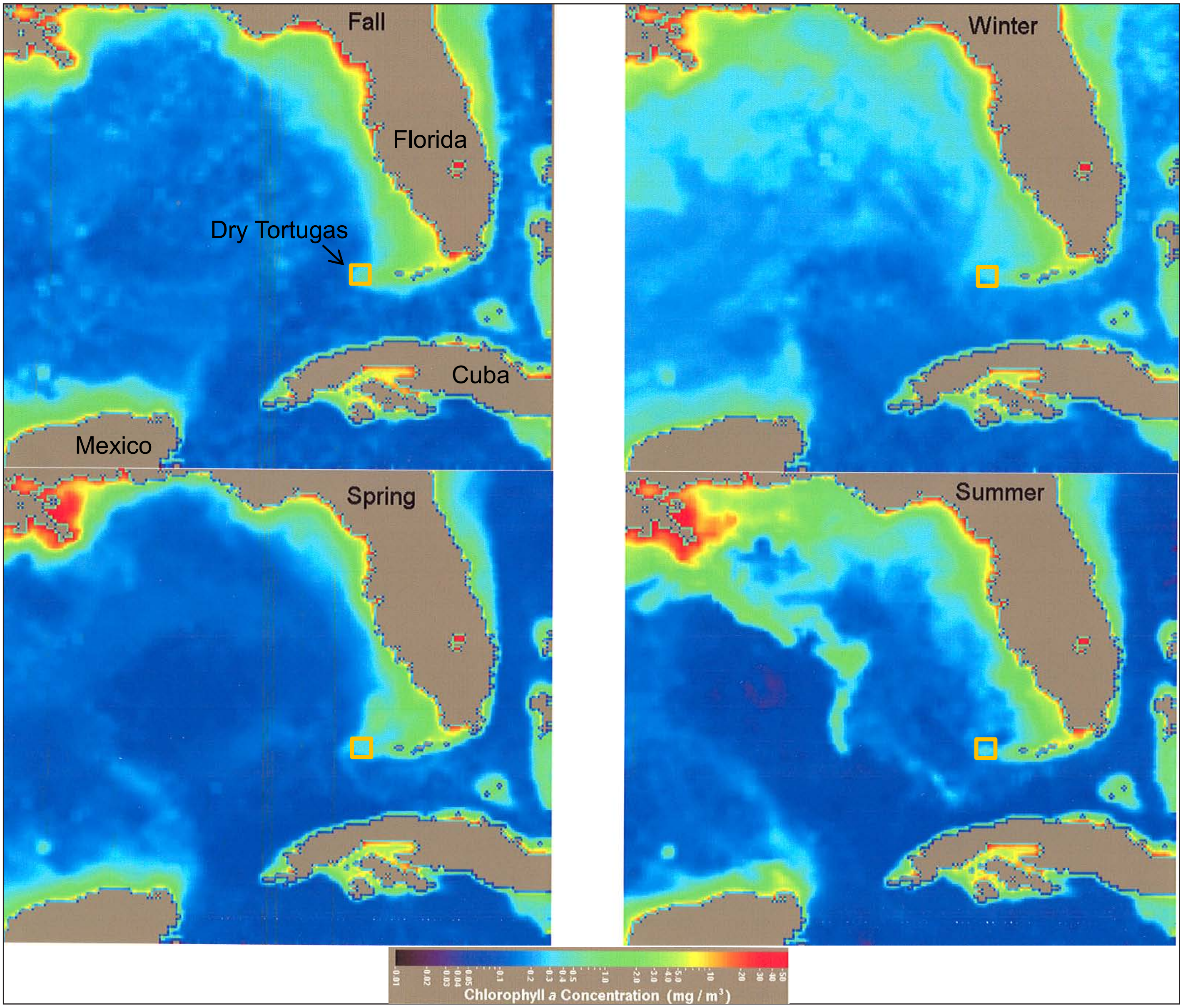


Figure 2.12. Maps of Chlorophyll-a concentration in the waters around Florida in November 2003 (fall), February 2004 (winter), May 2004, (spring) and July 2004 (summer) derived from Sea-Viewing Wide Field-of-View Sensor project. Source: http://oceancolor.gsfc.nasa.gov/SeaWiFS/.

SUMMARY AND CONCLUSION

The mapping component of the Tortugas integrated assessment project compiled and integrated existing data sets to generate the most up-to-date and comprehensive bathymetric and benthic habitat maps of the coral and hardbottom habitats in the TERSA. These comprehensive digital maps filled existing data gaps and provided base layers for the Tortugas integrated assessment study. Additionally, the maps have expanded the spatial extent of known coral reef and hard-bottom from just within the DRTO to include areas within the TERs (Riley's Hump and Tortugas Bank) as well as other areas less than 33 m deep between the Marquesas and DRTO. Detailed and up-to-date characterizations of oceanographic and hydrodynamic conditions from remotely sensed data are available for use in explaining long-term and broad-scale patterns in the distribution of marine organisms within the TERSA. These maps formed the foundations on which spatially explicit monitoring programs were established for reef fishes. These monitoring programs are the focus of the next few chapters of this report.

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Chapter 3: Reef Fishes and Macroinvertebrates of the Tortugas Ecological Reserve Area and the Dry Tortugas National Park

Christopher F.G. Jeffrey[1,2], Jerald S. Ault[3] and Steven G. Smith[3]

INTRODUCTION AND BACKGROUND

Fish assemblages are essential and prominent components of the marine ecosystems in the Dry Tortugas, which, for example, contain numerous known spawning aggregation sites (Schmidt et al., 1999). Fisheries in the Tortugas region include reef fish (e.g., snapper-grouper complex); invertebrate (conch, lobster and shrimp); and pelagic fisheries (e.g., Spanish Mackerel, *Scomberomorus maculatus*, and King Mackerel, *Scomberomorus cavalla*; Dolphinfish, *Coryphaena hippurus*; and sharks; Schmidt et al., 1999). Of these, reef fish and invertebrate fisheries are of the biggest concern to the Florida Keys National Marine Sanctuary (FKNMS) and the National Park Service (NPS). Fishes are public natural resources that form the basis of multibillion-dollar fisheries and supply local populations with much needed goods and services such as food, employment and recreation (Bannerot, 1990; Bohnsack et al., 1994; Johns et al., 2001). Prior to the establishment of the Tortugas Ecological Reserve (TER) in 2001, commercial fishing was allowed only outside of the Dry Tortugas National Park (DRTO). Then, about 105-110 commercial fishers operated 164 fishing vessels and targeted invertebrates (spiny lobster, *Panulirus argus;* shrimp and stone crabs) that comprised 63% of total landings in waters outside the DRTO (Leeworthy and Wiley, 2000). Commercial fishers also targeted reef fishes, Spanish and King Mackerels, and sharks (Leeworthy and Wiley, 2000). About 85% of commercial fishers in the Tortugas region were full-time fishermen that earned 100% of their income from fishing (Leeworthy and Wiley, 2000). The spatial extent of commercial fishing in the Tortugas region was further reduced when the reserves were implemented. However, these commercial fishers also fished elsewhere in the Florida Keys and only earned 47% of their total income from fishing in the Tortugas region (Leeworthy and Wiley, 2000). Although commercial fishing was prohibited within the DRTO since 1935, that activity still represented a major source of mortality for reef fishes in the Tortugas region until 2001 because many targeted species have home ranges larger than the spatial extents protected by the park.

Recreational fishing also occurs in the Tortugas region and is thought to be a major source of mortality for local reef fish assemblages (Ault et al., 2005a). Recreational fishers include residents of and visitors to Florida and are known to target mainly reef fish assemblages (Leeworthy and Wiley, 2000; Figure 3.1). For example, between 1981 and 1992, reef fishes made up 92% of average total recreational head-boat[A] landings in the Tortugas region (Bohnsack et al., 1994). Recreational fisheries target about 73 species of reef fish from about six families (Groupers and Snappers, Grunts, Jacks, Porgies and Hogfish; Ault et al., 2005a).

Figure 3.1. Assemblage of reef fish. Photo: University of Miami.

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A. Headboats are recreational fishing vessels that carry large groups of passengers that pay as individuals to go fishing (Bohnsack et al., 1994).

Prior to 2001, recreational fishing was permitted throughout the Tortugas region including the DRTO. Since 2001, however, recreational fishing has been prohibited within the TER, but it has continued within the park and in areas outside the reserves. In 2007, a Research Natural Area (RNA) was established within the national park that also prohibited all fishing within its boundaries. Now, recreational fishing continues in areas outside the ecological reserves and within the park but outside the RNAs. The total area of the Tortugas region now closed to all fishing is 685 km^2, 566 km^2 in the TER and 119 km^2 in the RNA within the DRTO.

NPS, The Florida Fish and Wildlife Conservation Commission (FWC) and NOAA's National Marine Fisheries Service (NMFS) have jurisdictional responsibilities for managing fishery resources in the Tortugas region. The Florida Marine Research Institute and NMFS (a component of FWC) are the primary agencies that compile information on fishery landings in the Tortugas region (Leeworthy and Wiley, 2000). The NPS has monitored reef fish populations and has conducted creel surveys to determine trends in fish abundance and recreational fishing effort within the park boundaries (Schmidt et al., 1999). The FWC monitors reef fish assemblages within state waters, whereas the NMFS monitors reef fish assemblages in federal waters including the DRTO. It is important to note that these management agencies have together enacted fishing regulations that are compatible across their jurisdictional areas.

HISTORICAL TRENDS AND PATTERNS IN FISHERIES LANDINGS AND REEF FISH ASSEMBLAGES OF THE TORTUGAS REGION, 1981 TO 1999

Determining the long-term trends of reef fisheries and reef fish assemblages in the Tortugas region has long been the focus of local management agencies. Although several factors are known to affect reef fish assemblage structure and biomass, commercial and recreational fishing have been the primary agents shaping reef fish assemblages in the Tortugas region since the 1920s (Bohnsack et al., 2004; Ault et al., 2005a). Based on landings and fishing effort data, the NMFS concluded that sharp declines in recreational landings of reef fishes (e.g., Nassau Grouper, *Epinephelus striatus*, and King Mackerel) throughout from the Florida Keys between 1981 and 1994 correlated significantly with a substantial (500%) increase in registered recreational fishing boats (Bohnsack et al., 1994; Ault et al., 2005a). In response to the observed fishery declines, state and federal management agencies enacted a suite of 60 or more regulations between 1979 and 1992 (Bohnsack et al., 1994). Regulations included minimum size limits, seasonal closures and recreational bag limits among others to protect fishery species; they also closed fisheries for Nassau Grouper, Goliath Grouper (*Epinephelus itajara*) and queen conch (*Eustrombus gigas*; Bohnasck et al., 1994). These regulations and fishery closures were designed to reduce total fishing mortality for targeted reef fishes and stabilize fishery yields. However, these regulations alone were ineffective in rejuvenating local fisheries largely because a species-based approach was being used to manage a multi-species fishery (Bohnsack et al., 1994; Ault et al., 1998). For example, fishery independent data on reef fishes in the Florida Keys and Tortugas region between 1979 to 1996 indicated that intense historical fishing resulted in about 50 reef fishes (species of snappers, groupers, grunts, jacks, porgies and hogfish) being harvested unsustainably by U.S. federal overfishing standards (Ault et al., 1998; Ault et al., 2005a). Furthermore, several reef fishes in the Florida Keys were considered serially overfished because stocks of large and desirable species (e.g., Goliath; Red, *Epinephelus morio*; and Black, *Mycteroperca bonaci*, Groupers) were depleted and had become rare (Ault et al., 1998; Figure 3.2). The spawning stock biomass of Black Grouper also was

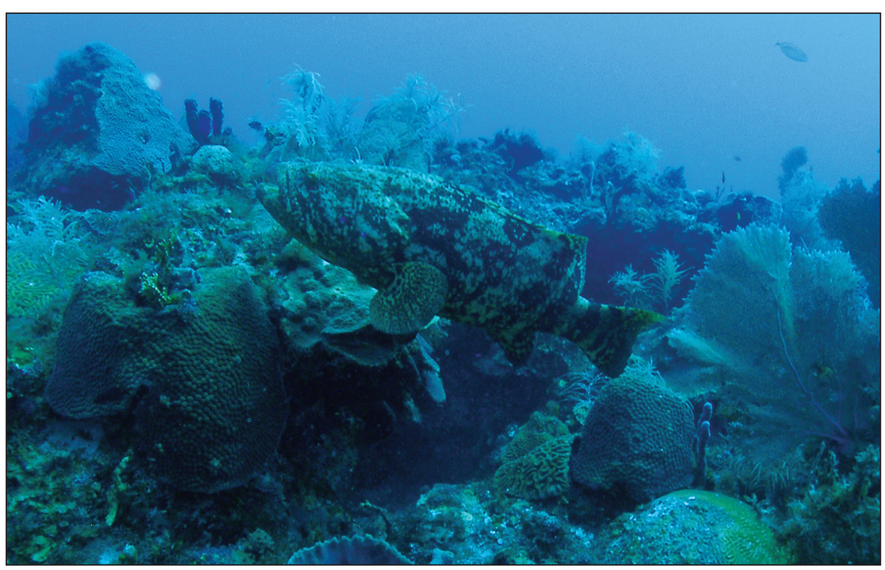

*Figure 3.2. The species, Goliath Grouper (*Epinephelus itajara*). Photo: NCCOS Center for Coastal Fisheries and Habitat Research (CCFHR).*

found to be <10% of its historical size (Ault et al., 2005a), and the average size of that species in 2001 was 40% smaller than its average size in 1940 (Ault et al., 2001). These trends suggest that management options were unsuccessful in halting the demise of reef fish and invertebrate fisheries in the Florida Keys and Tortugas region.

ECOSYSTEM-BASED APPROACHES TO REBUILDING AND MONITORING REEF FISH ASSEMBLAGES, 2000 TO 2007

The sanctuary preservation areas (SPAs) and the ecological reserves within the FKNMS and the RNA within the DRTO (hereafter no-take reserves) were all implemented to help reduce consumptive use of resources (e.g., fishing) and indirectly rebuild reef fish populations in the Florida Keys and Tortugas region by acting as refugia from fishing. Implementation of fully protected areas represented a substantial departure from previous management approaches used in the Florida Keys and represent an ecosystem-based approach to reducing the negative effects of fisheries on reef fish assemblages. Rather than continuing to implement a suite of management actions to protect individual species or fisheries, no-take reserves offered protection from extractive and destructive human activities to all ecosystem components occurring within their boundaries. Expectations were that over time, the SPAs and reserves would result in significant increases in abundance and biomass of exploited reef fishes. Additional expectations were that continued increases in abundance and biomass within the reserves ultimately would result in future export of fishery resources from reserves to adjacent unprotected areas via either larval dispersal or adult fish movements (Bohnsack, 1998; Roberts et al., 2001; Ault et al., 2005a). The expectation of larval dispersal from no-take areas in the Tortugas region to the Florida Keys was not unrealistic because of the region's upstream location in oceanic currents relative to the rest of the Florida Keys (Lee and Williams, 1999).

Determining the efficacy of established no-take areas in rebuilding reef fish populations and protecting ecosystem components has been a goal of monitoring and research programs in the Florida Keys and the Tortugas region. Since 1999, a multidisciplinary team of scientists integrated fishery-related information with data on biological, oceanographic and habitat components of ecosystems within a Fishery Systems Science (FSS) framework (Figure 3.3; Ault et al., 2005a; Bartholomew et al., 2008). The FSS framework, described in detail in Ault et al. (2005a), is being used to understand the impacts of fisheries on reef fish populations and community dynamics and to evaluate performance of reserves in the Florida Keys and the Dry Tortugas region. The FSS framework uses "age-structured stock production" models to describe spatial and temporal dynamics of reef fish assemblages and to identify impacts of fishing on selected reef fish populations (Ault et al., 2005a,b). Impacts of fishing on reef fishes are determined by comparing demographic metrics derived for a surveyed reef fish population against federally mandated minimum standards (Ault et al., 2005a,b). If the derived metrics for the surveyed reef fish population are below the minimum standard, then the population is considered overfished.

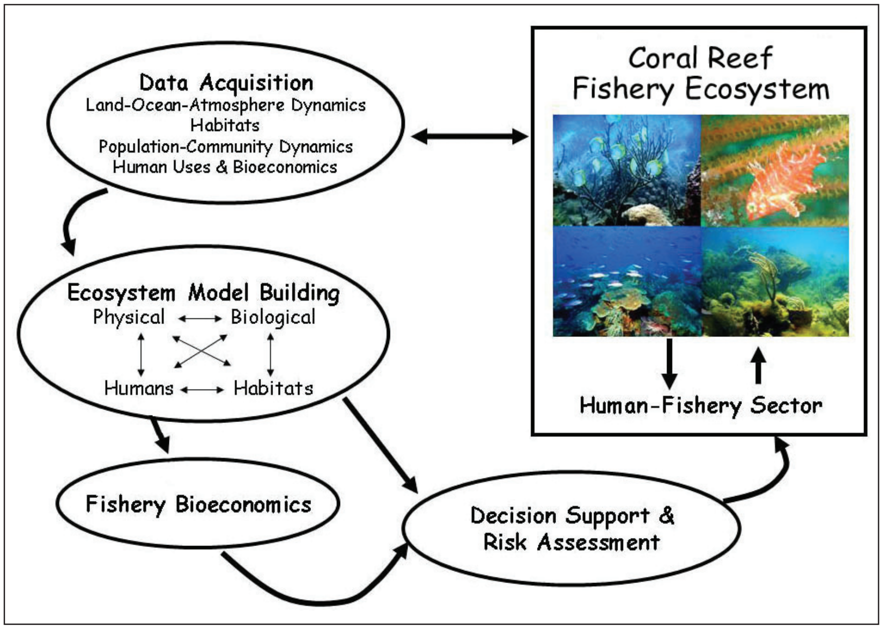

Figure 3.3. Overview of the components in a system science approach to multispecies fishery management on coral reef ecosystems. Source: Ault et al., 2005a.

At the core of the FSS framework is a monitoring program that utilizes synoptic visual surveys within a stratified random sampling design to assess the occurrence, abundance, and spatial distribution of reef fishes, lobsters and stony corals on hard bottom habitats in the Florida Keys and the Tortugas region (Ault et al., 2005a,b;

Bartholomew et al., 2008). Data from these visual surveys are analyzed to provide unbiased demographic estimates of surveyed organisms to identify impacts of fishing on reef fish populations as described previously (Ault et al., 1998, 2003, 2005a,b); to inform decisions regarding the potential implementation and design of no-take fishery reserves (Meester et al., 2001, 2004; Ault et al., 2006a,b, 2007; Bartholomew et al., 2008); and to evaluate the efficacy of no-take reserves (Ault et al., 2006a,b, 2007). Specific data collected include the average size and abundance of reef fish individuals by species as well as a suite of environmental variables that characterize the types and composition of hard bottom habitats (Franklin et al., 2003; Ault et al., 2005a,b; Miller et al., 2006). The environmental variables are used as covariates in statistical models that describe spatial and temporal patterns in the abundance of reef fishes, lobsters and stony corals (Ault et al., 2005a,b). Environmental variables are also used to characterize, map, and assess the condition of benthic communities in the region (Franklin et al., 2003; Miller et al., 2006). The following section reviews the major findings of the FSS framework for the DRTO, which were summarized from Ault et al. (2006a,b, 2007). Specific details on the sampling design, survey methods and statistical analyses by the FSS framework are given in several publications (Table 3.1).

Table 3.1. Publications describing trends in reef fish assemblages in the Tortugas region and the development of a Fisheries Systems Science model for managing reef fisheries. Source: Brandt et al., 2009.

Year	Publication
1986	Bohnsack, J.A. and S.P. Bannerot. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Tech. Report NMFS 41. 15 p.
1998	Ault, J.S., J.A. Bohnsack, and G.A. Meester. A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. Fishery Bulletin 96:395-414.
1999	Ault, J.S., Diaz, G.A., Smith, S.G., Luo, J. and J.E. Serafy. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. North American Journal of Fisheries Management 19:696-712.
1999	Bohnsack, J.A., D.B. McClellan, D.E. Harper, G.S. Davenport, G.J. Konoval, A. Eklund, J.P. Contillo, S.K. Bolden, P.C. Fischel, G.S. Sandorf, J.C. Javech, M.W. White, M.H. Pickett, M.W. Hulsbeck, J.L. Tobias, J.S. Ault, G.A. Meester, S.G. Smith, and J. Luo. Baseline data for evaluating reef fish populations in the Florida Keys, 1979-1998. NOAA Technical Memorandum NMFS-SEFSC-427. 61p.
2001	Ault, J.S., S.G. Smith, G.A. Meester, J. Luo, and J.A. Bohnsack. Site characterization for Biscayne National Park: assessment of fisheries resources and habitats. NOAA Technical Memorandum NMFS-SEFSC-468. 185 p.
2002	Ault, J.S., S.G. Smith, J. Luo, G. A. Meester, J.A. Bohnsack, and S.L. Miller. Baseline multispecies coral reef fish stock assessment for the Dry Tortugas. NOAA Technical Memorandum NMFS-SEFSC-487. 117 p.
2002	Bohnsack, J.A., D.E. Harper, D.B. McClellan, D.L. Sutherland and M. White. Resource survey of fishes within Looe Key National Marine Sanctuary, 1983. NOAA Technical Memorandum NOS-NCCOS-CCMA-160 and NMFS-SERSC-478. 327 p.
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2005	Ault, J.S., J.A. Bohnsack, S.G. Smith, and J.G. Luo. Towards sustainable multispecies fisheries in the Florida, USA, coral reef ecosystem. Bulletin of Marine Science 76:595-622.
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STATUS AND TRENDS OF CORAL REEF FISH POPULATIONS IN THE TORTUGAS ECOLOGICAL RESERVE STUDY AREA, 1999 – 2006

Ault et al., (2007) described several metrics of reef fish populations obtained from visual surveys conducted during 1999-2000, 2002, 2004 and 2006. Metrics were calculated for eight commercially important (fished or exploited) species and 14 non-fished species (Table 3.2). Derived metrics from the surveys conducted during 1999-2000 were considered the baseline condition to which metrics from subsequent years were compared to determine statistically significant biennial trends in the selected reef fish populations. Biennial trends were determined for the entire domain (DRTO) and two strata: inside and outside the RNA (Figure 3.4). It is important to note that because the RNA was established in 2007, all metrics from surveys conducted before 2007 represent baseline conditions relative to determining future benefits of the RNA. Derived metrics were species richness (all species included and snapper-grouper complex) as well as frequency of species occurrence and mean density of selected exploited and no-exploited fishes.

*Table 3.2. Percent changes in population mean density of selected exploited and non-target fish species from baseline years 1999-2000 relative to the survey years 2002, 2004 and 2006 in the DRTO sampling domain. Statistically significant changes from baseline years are shown as: ns=not significant; * = p<0.05; ** = p<0.01; *** = p<0.001. Source: Ault et al., 2007.*

	2002		2004		2006	
Taxa	**Change**	**(%)**	**Change**	**(%)**	**Change**	**(%)**
Exploited						
Red Grouper (*Epinephelus morio*)	13.3	ns	-9.3	ns	-16.4	ns
Black Grouper (*Mycteroperca bonaci*)	212.8	**	131	***	45.9	ns
Mutton Snapper (*Lutjanus analis*)	191	ns	146.3	***	94.5	**
Gray Snapper (*Lutjanus griseus*)	-0.8	ns	286.3	ns	-55.1	ns
Yellowtail Snapper (*Ocyurus chrysurus*)	100.4	*	128.4	***	-21.6	ns
Hogfish (*Lachnolaimus maximus*)	-6.1	ns	-24.6	ns	-15.4	ns
White Grunt (*Haemulon plumierii*)	-38.8	*	3.8	ns	-0.4	ns
Bluestriped Grunt (*Haemulon sciurus*)	141.7	ns	260	ns	0.3	ns
Unexploited						
Ocean Surgeon (*Acanthurus bahianus*)	-30.5	ns	-8.7	ns	46.1	*
Blue Tang (*Acanthurus coeruleus*)	83.2	***	97.3	***	24.6	ns
Foureye Butterflyfish (*Chaetodon capistratus*)	53.8	ns	28.2	ns	-25.5	ns
Spotfin Butterflyfish (*Chaetodon ocellatus*)	38.1	ns	0.3	ns	-39.2	***
Bluehead Wrasse (*Thalassoma bifasciatum*)	84.4	***	52.9	***	33.6	***
Spotted Goatfish (*Pseudupeneus maculatus*)	16.7	ns	172.3	***	128.8	***
Blue Angelfish (*Holacanthus bermudensis*)	87.7	**	27.1	ns	-32.6	*
Gray Angelfish (*Pomacanthus arcuatus*)	25.9	ns	115.2	ns	28.7	*
Purple Reeffish (*Chromis scotti*)	453.9	*	243.3	***	86.1	*
Bicolor Damselfish (*Stegastes partitus*)	80.6	**	16.6	ns	-29.5	ns
Cocoa Damselfish (*Stegastes variabilis*)	20.3	ns	6.1	ns	45.9	***
Striped Parrotfish (*Scarus iseri*)	12.8	ns	9.8	ns	8.7	ns
Redband Parrotfish (*Sparisoma aurofrenatum*)	-11.3	ns	56.3	ns	-29.7	ns
Stoplight Parrotfish (*Sparisoma viride*)	38.4	ns	85.7	***	-23.3	ns

Ault et al. (2006a,b) reported spatial and temporal patterns for reef fish populations in the DRTO. Their data showed that reef fish biodiversity was greatest in highly rugose habitats, and that populations of exploited and unexploited species within the RNA were similar to those found in adjacent non-RNA habitats. In addition, they observed no significant increase or decrease in mean species richness over time within the DRTO for most years except in 2006, when species increased to 39.9 ± 0.8 species (p<0.001) from the 1999-2000 baseline of 34.6 ± 0.9 species (Ault et al., 2006,b). Mean species richness of the snapper-grouper complex increased sig-

nificantly from the 1999-2000 baseline of 7.6 ± 0.3 species to 8.3 ± 0.3 species in 2002 ($p<0.01$) and 8.2 ± 0.2 species in 2006 ($p<0.05$). Thus, prior to the implementation of the RNA, it seemed that species richness was relatively stable between 1999 and 2006 inside and outside the RNA. This temporal pattern in species richness inside and outside the RNA was similar to that observed for the entire park.

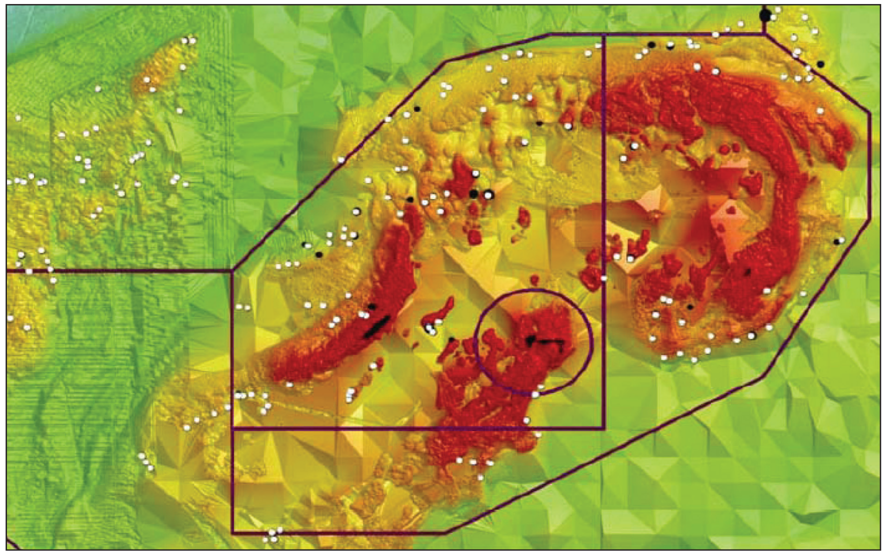

*Figure 3.4. Locations of reef fish visual census surveys conducted within habitat grids (177 m^2) in the Tortugas region. Dark circles show positive relative density (number of animals per 177 m^2) of pre-exploited phase Black Grouper (*Mycteroperca bonaci*), whereas open white circles indicate that no Black Grouper were seen during four replicate dives within a given habitat location. Source: adapted from Ault et al.,2007.*

Temporal trends in the mean frequency of occurrence of exploited species within the park were variable over time and among species. Six of eight exploited species showed either a significant increase or decrease in mean frequency of occurrence over time (Ault et al., 2006b). Some species consistently increased in mean frequency of occurrence at sites over time. The occurrence of black grouper at sites increased from 25.8 ± 3.7 sites in 1999-2000 to 35.7 ± 4.9 sites in 2002 ($p<0.05$) and 36.7 ± 3.2 sites in 2004 ($p<0.01$), but then it decreased to 24.0 ± 3.1 sites in 2006 ($p>0.05$). Likewise, the mean frequency of occurrence of Mutton Snapper (*Lutjanus analis*) at sites progressively increased from the baseline of 14.8 ± 3.2 sites in 1999-2000 to 24.4 ± 5.1 sites in 2002 ($p>0.05$) to 26.4 ± 3.1 sites in 2004 ($p<0.01$) and to 30.2 ± 4.5 sites in 2006 ($p<0.01$).

Conversely, some species showed a consistent decline in the mean frequency of occurrence over time. The Red Grouper consistently decreased in its frequency of occurrence at sites such that it occurred at significantly fewer sites in 2006 (55.0 ± 4.4 sites, $p<0.05$) compared with 1999-2000 baseline of 63.9 ± 4.2 sites. Hogfish showed a significant decline in mean frequency of occurrence at sites in 2002 and 2004 ($p<0.05$) compared with the 1999-2000 baseline estimate, but the decrease in frequency of occurrence was progressively smaller every two years such that by 2006, the difference from the baseline estimate was not significant (Ault et al., 2006b). Interestingly, more exploited species on average had lower site frequencies than non exploited species, but it is uncertain whether that pattern is real or a function of the species selected for analysis. Four of eight of the exploited species occurred at 50% or more of surveys sites, whereas seven of 14 non-exploited species reported by Ault et al. (2006b) occurred at 50% or more of the sites.

Temporal trends in the percent mean frequency of occurrence of the 14 non-target species were variable over time and among species. Ten of 14 non-exploited species showed either a significant increase or decrease in proportion of sites at which they occurred over time (Ault et al., 2006b). Examples of non-exploited species that showed a significant increase ($p<0.05$) in percent frequency of occurrence included Ocean Surgeonfish (*Acanthurus bahianus*), Bluehead Wrasse (*Thalassoma bifasciatum*), Purple Reeffish (*Chromis scotti*), Spotted Goatfish (*Pseudupeneus maculatus*) and Cocoa Damselfish (*Stegastes variabilis*). The Spotfin Butterflyfish (*Chaetodon ocellatus*) was the only non-exploited species that ultimately showed a significant decrease in its occurrence at sites in 2006 ($p<0.01$) when compared with the 1999-2000 baseline. The Redband Parrotfish (*Sparisoma aurofrenatum*) initially decreased in mean frequency of occurrence in 2002 ($p<0.01$), but by 2006, its mean frequency of occurrence increased such that the difference relative to the 1999-2000 baseline was insignificant ($p>0.05$).

Likewise, temporal trends in density of exploited species varied over time and among species, with the abundance of some species increasing, decreasing, or remaining the same. Four of eight exploited species analyzed by Ault et al. (2006b) either increased or decreased significantly above or below 1999-2000 baseline

estimates. Domain-wide estimates of Black Grouper and Yellowtail Snapper (*Ocyurus chrysurus*) initially increased significantly in 2002 and 2004 ($p<0.05$), then decreased such that by 2006, the increase above the 1999-2000 baseline was no longer significant ($p>0.01$). Mutton Snapper (*Lutjanus analis*) showed an increase in density in 2004 and 2006 ($p<0.01$). Mean density of White Grunt (*Haemulon plumierii*) initially decreased in 2002 ($p<0.05$), but returned to baseline estimates in 2004 and 2006. Purple reeffish consistently increased in mean density above the 1999-2000 baseline estimates.

Temporal trends in the density of non-exploited species were highly variable over time and among species. Ten of 14 species showed significant increases or decreases in mean densities of fishes above or below 1999-2000 baselines ($p<0.05$). Mean densities of Ocean Surgeonfish, Bluehead Wrasse, Spotted Goatfish, Gray Angelfish (*Pomacanthus arcuatus*), Purple Reeffish and Cocoa Damselfish in 2006 were significantly higher than 1999-2000 baseline densities. Blue Tang (*Acanthurus coeruleus*) and Stoplight Parrotfish (*Sparisoma viride*) initially increased in density ($p<0.05$), but by 2006, their abundance reverted to around baseline levels. Mean densities of Spotfin Butterflyfish and Blue Angelfish (*Pomacanthus bermudensis*) decreased significantly below the baseline by 2006. Mean densities of other species (Foureye Butterflyfish, *Chaetodon capistratus*; Bicolor Damselfish,*Stegases partitus*; Striped Parrotfish, *Scarus iseri*; and Redband Parrotfish) also varied over time but were not significantly different from baseline estimates ($p>0.05$).

SUMMARY AND CONCLUSIONS

Ault et al. (2006a,b) tracked temporal variation in reef fish metrics based on the statistical covariance between reef fish abundance and coral reef-habitat types to determine the status and trends of reef fish populations in the DRTO. Using similar data and analytical techniques, Ault et al. (2005a,b, 2007) also characterized reef fishes and tracked their temporal trends in the TER and the wider Tortugas region, the FKNMS to evaluate the effectiveness of no-take reserves and other management approaches in rebuilding reef fish populations. In general, the spatial and temporal trends observed in reef fish populations within the park mimicked those observed in the TER and wider Tortugas ecological region, and the Florida Keys. The Tortugas region as a whole likely experienced an early increase in the biomass of exploited species within a few years of implementation of the TER. This early increase is typical of marine reserves although full recovery of reef fish populations is expected to take decades (Russ et al., 2004). Ault et al. (2006a,b, 2007) observed significantly greater abundance, frequency of occurrence, and shifts toward larger sizes of Black and Red Groupers and Mutton Snappers in the TER North and throughout the Tortugas region within four to six years of its establishment. Furthermore, they did not find any significant declines in the abundance exploited species within the TER. Thus, reef fish populations in the park may have benefited from the protection offered by the adjacent TER.

However, other factors may have contributed to enhanced reef populations in the Tortugas region. Spatial and temporal trends observed within the park and the Tortugas region possibly resulted from previously enacted management actions acting synergistically with reserve implementation. Increased minimum size limits, reduced bag limits, and other similar management actions that reduced fishing mortality on some reef fish populations could have augmented the protection offered by area-closures, and ultimately could have increased the abundance of exploited species in the park and throughout the Tortugas region. Furthermore, reef fish populations in the park and surrounding region may have been positively or negatively affected by environmental conditions and episodic disturbances such as hurricanes, which may have randomly affected recruitment of exploited and unexploited species in any given year. Such random environmental variation may be a logical explanation for the varied trends in reef fish abundance and biomass observed in the Tortugas region.

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Chapter 4: Characterization of Benthic Communities

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INTRODUCTION AND BACKGROUND

The overall objective of NOAA Center for Coastal Fisheries and Habitat Research's (CCFHR) biogeographic approach in the Tortugas was to examine the effects of implementing a marine reserve on reef fish assemblages and benthic composition. Energy flow across reef-sand boundaries is critical to understanding reef function. For example, reef fish may forage in sand, algae and seagrass flats and import significant amounts of nutrients when they return to the reef (Meyer et al., 1983). Previous work on the west Florida shelf suggests that benthic primary production is the major energetic source supporting fish biomass (Currin et al., 2000). As the majority of the Tortugas Ecological Reserve (TER) is non-coral habitat, the structure and composition of fish communities near the reef interface may be a likely area to detect a reserve effect (Burke et al., 2004). Mapping of habitat types and interface locations was conducted at a variety of scales, including satellite and aerial imagery, towed video/sonar and multibeam sonar (Chapter 2; Fonseca et al., 2006). This chapter describes the fine-scale (meters) benthic characterization designed to add a habitat component to the annual fish surveys and to provide covariates for explaining spatial patterns in fish assemblages at sand-reef interfaces (Chapter 5). This chapter also summarizes benthic habitat studies conducted by other research institutions in the Tortugas region .

DATA COLLECTION AND ANALYSIS METHODS

To test management effects, an integrated Before-After Control Impact (BACI) design was used. Thirty permanent monitoring sites (Figure 4.1) were randomly selected along the reef-sand interface in 2001 (depth 15-32 m), using the procedures outlined by Burke et al. (2004). Ten sites were established in each of three strata: "Reserve" (within TER North), "Park" (within Dry Tortugas National Park [DRTO]; several park sites are located within the RNA recently designated within DRTO) and "Open", unprotected areas. Sites within each stratum were equally allocated on either side of the predominant direction of current flow across the banks, resulting in a total of six categories: Park North (PN), Park South (PS), Reserve North (RN), Reserve South (RS), Out North (ON) and Out South (OS).

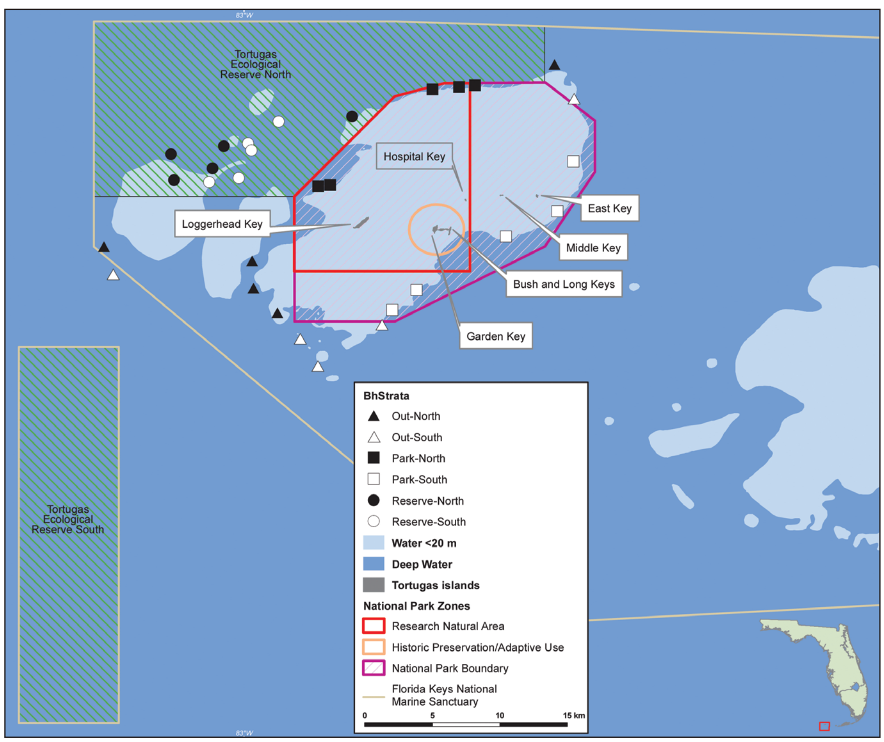

Figure 4.1. NCCOS Center for Coastal Fisheries and Habitat Research's (CCFHR) 30 permanent stations in the Tortugas.

Each year (2001-2005, 2007-2009), divers surveyed two 30 m transects perpendicular to the interface—one transect into the sand, and one onto the reef. Fish surveys and benthic transects were conducted concurrently. If the site marker could not be located in a given year, a new marker was installed in the same general area. Digital video transects of the benthos were collected from 2001-2004 along the same 30 m transects used for the fish surveys, in both the reef and sand habitats. Video was collected

1. NOAA/NOS/NCCOS/Center for Coastal Fisheries and Habitat Research
2. Smithsonian Marine Station

in 2001 at a camera height approximately 1.0 m above the bottom; however, subsequent analysis suggested the video quality at that height did not provide adequate resolution of certain taxonomic groups (e.g., benthic microalgae; crustose coralline algae, CCA: and certain scleractinian coral species). In 2002-2004, video was taken at a reduced, fixed distance of 0.4 m. Non-overlapping still photos were frame-selected from the video using Sony DVGate and analyzed using Point Count 99. Due to intensive processing time and the anticipated change to still photography, video collected in 2004 has been archived but not analyzed. Diversity and species richness were calculated for scleractinian corals only (fire corals were excluded), and “unidentified coral” (e.g., those where the photographic resolution was not detailed enough to enable identification) was included in the calculation.

Beginning in 2005, digital still images replaced video methodologies, improving resolution and significantly reducing image preparation time. Photos were taken every meter along the 30 m transect at a fixed height of 0.4 m, and percent cover was determined using Coral Point Count software (Kohler and Gill, 2006). Preliminary comparisons of the video and still photo techniques at a small subset of sites in 2005 showed no significant differences in the results of the two methods. CCFHR re-surveyed the 30 permanent transects using the still photo methodology in August 2007 with concurrent video transects for additional method calibration.

The benthic data could not be statistically analyzed using a repeated measures design due to changes in photographic techniques. Instead, years with similar methodologies were pooled for analysis (e.g., 2001, 2002-2003 and 2005) using Statistica 4.0. Percent cover data were tested for normality using Kolmogorov-Smirnov test and for homogeneity of variance using Levene’s test. Effects of management strata were tested using using Analysis of Variance (ANOVA) for 2001 and 2005; the 2002-2003 data used a two-way ANOVA to test for effects of strata and year. Post-hoc comparisons were made using Tukey’s HSD test; if the variance was not homogenous post-hoc comparisons were made using Dunnett’s test. Data that did not meet parametric assumptions after arcsine square root transformation were analyzed using nonparametric Kruskal-Wallis ANOVA or the Scheirer-Ray-Hare nonparametric two-way ANOVA. The subdivisions (north and south) in each stratum had no significant effect, so all ten sites within each stratum were pooled for analysis.

Multivariate analyses were conducted using Primer 6.0 to explore the relationship among sites and strata in a given year. Percent cover of benthic functional groups (coral, fire coral, macroalgae, sponge, octocoral, CCA, hard substrate, seagrass, microalgae and soft substrate, other invertebrates and unknown/manmade) was arcsine square root transformed and a Principal Components Analysis (PCA) was conducted to examine which benthic categories account for the variability observed among sites. Non-metric multi-dimensional scaling (MDS) ordination was applied to understand the relationships among sites. MDS results were supported by hierarchal cluster analysis based on group averages and based on Bray-Curtis similarity indices for functional groups.

RESULTS AND DISCUSSION

Benthic Cover by Management Stratum

The sand transects had scant biological cover, and the limited resolution of the photographic techniques made it difficult to reliably identify benthic microalgae. Therefore, only the reef transect data will be discussed here. Percent cover for the major benthic taxonomic and abiotic groups on the reef transects is presented in Figure 4.2. As mentioned above, the years are not always strictly comparable due to differences in photographic methodologies and therefore were analyzed separately. Relatively few statistically significant differences were found between management strata, and effects were often inconsistent across years. For example, in 2001, rock/rubble was the only category to show a statistical difference among strata, with higher cover in DRTO ($F_{2,27}$=6.617, p=0.005) than in TER (Tukey’s HSD p=0.017) or unprotected areas (p=0.005). Octocoral cover was usually lowest in DRTO, but the only statistically significant difference was in 2002-2003 ($F_{2,54}$=3.398, p=0.041), with higher cover in TER than DRTO (Tukey’s HSD p=0.033). Temporal differences could be analyzed for 2002-2003 since they shared a common methodology; the only significant difference among those years was higher primary production (macroalgae, CCA and seagrasses) in 2003 than in 2002 ($F_{1,54}$=4.743, p=0.007), with a concomitant decrease in rock rubble ($F_{1,54}$=4.101, p=0.048).

Coral cover in TER (Figure 4.2) was typically higher than in DRTO or in unprotected areas, but statistically significant only for 2002-2003 ($F_{2,54}$=6.688, p=0.003). Coral cover primarily consisted of great star coral (*Montastraea cavernosa)* and the boulder star coral (*Montastraea annularis* complex; mostly mountainous star coral, *Montastraea faveolata*); these species were present at most sites. Massive starlet coral (*Siderastrea siderea)* and boulder brain coral *(Colpophyllia natans)* form a secondary group of framework-building species at these sites, while brain coral (*Diploria* spp.) were relatively uncommon. Among non-framework builders, the most common species were cactus coral (*Mycetophillia* spp.) and lettuce coral (*Agaricia* spp.), with occasional maze coral (*Meandrina meandrites)*, mustard hill coral (*Porites astreoides)*, blushing star coral (*Stephanocoenia intersepta)* and rough starlet coral (*Siderastrea radians)*.

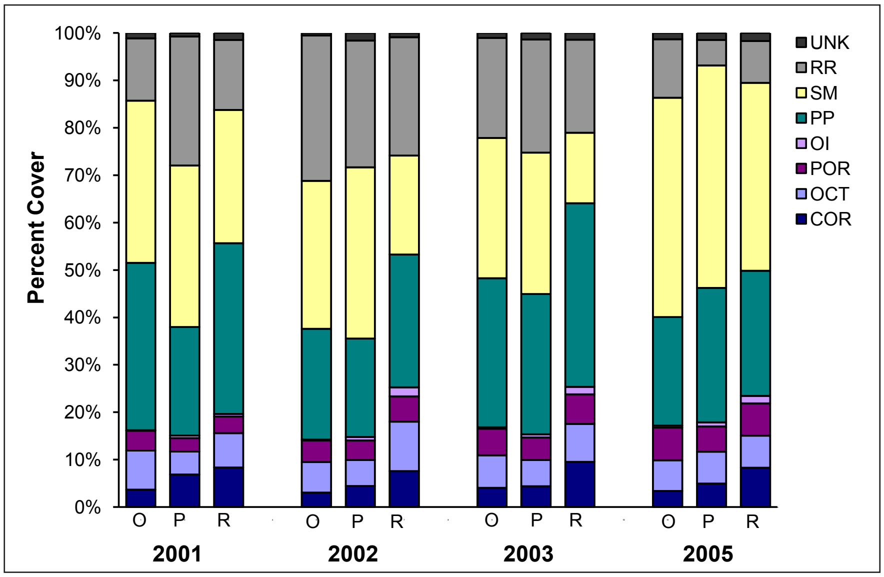

Figure 4.2. Percent cover on benthic reef transects in each of the three strata: O = unprotected, P = Dry Tortugas National Park (DRTO), R = Tortugas Ecological Reserve (TER). COR = coral, OCT = octocoral, POR = sponges, OI = other invertebrates, PP = primary producers, SM = sand and benthic microalgae, RR = rock and rubble, UNK = unknown. Source: NCCOS CCFHR.

Rare species included elliptical star coral (*Dichoecoenia stokesii)*, solitary disk coral (*Scolymia* spp.), smooth star coral *(Solenastrea bournoni)* and smooth flower coral (*Eusmilia fastigiata)*. These interface sites are relatively deep (15-32 m) and branching corals are present but not abundant. Diffuse ivory bush coral (*Oculina diffusa)*, ten-ray star coral (*Madracis decactis)*,yellow pencil coral (*Madracis mirabilis)*, and finger coral (*Porites porites*) were occasionally observed. Acroporids can be a major framework-builder on shallow Tortugas reefs, at least historically (Davis, 1982), but staghorn coral (*Acropora cervicornis*) was rare at our deep sites and elkhorn coral (*Acropora palmata*) was not observed.

Richness and diversity of scleractinian coral species in 2002-2003 tended to be higher in TER than the other strata, but this pattern was not statistically significant. Increased photographic resolution in 2005 allowed better species identification; however there were no significant differences in richness ($F_{2,27}$=0.138, p=0.872) or diversity ($F_{2,27}$=1.180, p=0.323) among strata (Figure 4.3). While diversity was correlated with depth (r=0.386, p=0.035), richness and depth were not correlated (r=0.214, p=0.256). The greater photographic resolution in 2005 also improved taxonomic identification of macroalgae. Predominant genera were *Dictyota*, *Halimeda*, and *Lobophora*; with *Codium* moderately abundant at DRTO sites.

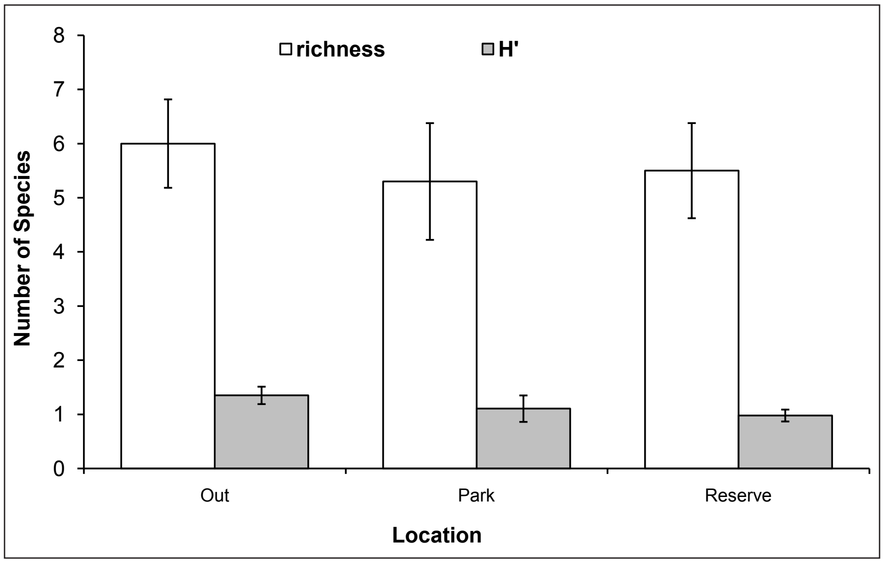

Figure 4.3. Species richness and diversity for scleractinian corals in 2005. Source: NCCOS CCFHR.

The lack of statistically significant effects among strata implies that management strategies have had little effect on benthic resources, but differences in methods and strata make temporal comparisons difficult. Fur-

thermore, differences between sites may have swamped variability among strata. The experimental design emphasized replication at the stratum level rather than the site level, but additional transects at each site may have helped stabilize some of the site variability.

Benthic Cover by Site

Relationships among sites are best examined in years that share similar methodologies. Figures 4.4-4.11 illustrate percent cover for the major biological categories on the reef transects at each site, and are described in more detail below.

2001

Coral cover in 2001 was highest at RS10262 and PN3120 (Figure 4.4). Coral was present at all 10 unprotected sites, but the average coral cover in DRTO and TER was reduced by the presence of two sites in each of the protected areas with coral cover <0.7%. TER had the most sites with fire coral (*Millepora* sp.), though overall cover of fire coral did not differ among strata ($F_{2,27}$=2.068, p=0.146). The unprotected stratum had the sites with the highest octocoral cover (ON6772 and OS7675). Sponge cover was relatively consistent among sites. Macroalgal cover in DRTO was highly variable (i.e., stratum included the sites with the highest and lowest algal cover). Video resolution in 2001 was not sufficient to reliably identify seagrass or CCA on any of the transects. PN632 was almost entirely sand (76%), and was the only site at which no biological category had a cover greater than 5%.

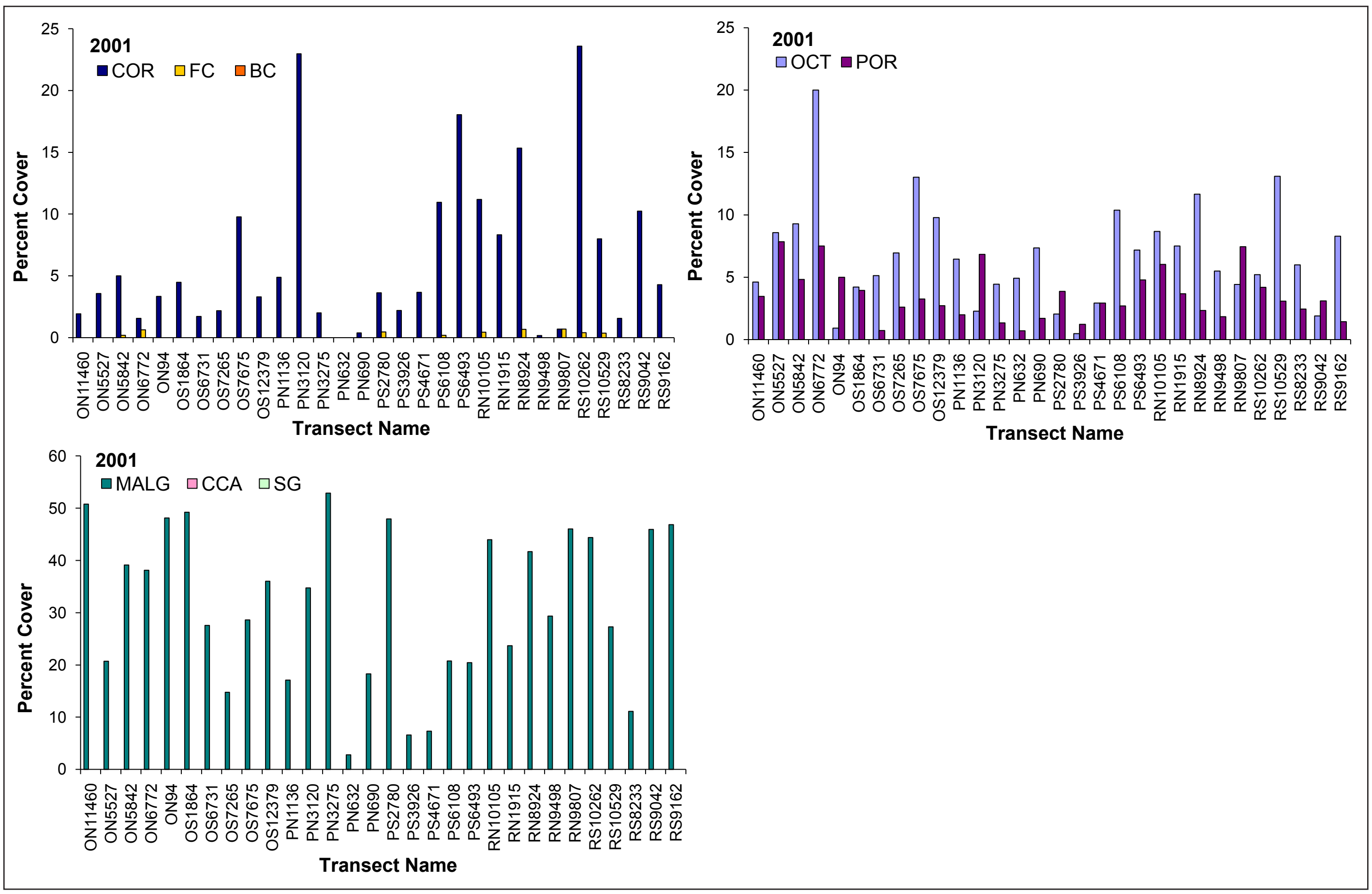

Figure 4.4. Benthic cover of biota on reef transects in 2001. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

The PCA defined 59.7% of the variation in PC1 with the three dominant functional groups of soft substrate, macroalgae and coral. With the addition of hard substrate, PC2 increased the cumulative percent variation explained to 80.0% (data not shown). Several distinct groups were seen in the MDS plot and supported by group-averaged cluster analysis from Bray-Curtis similarities (Figure 4.5). Sites did not cluster by management stratum. The cluster on the right-hand side of the plot contains the sites with the highest proportion of sand. Within that group, the sites with the highest octocoral cover (OS7265 and RS8233) clustered together, as did

the only sites in that group with macroalgal cover of >20% (OS6731 and RN9498). A second main cluster at the top of the MDS contains the two sites with the highest coverage of rock/rubble (54.4% at PN1136, 45.7% at PN690). ON94 was an outlier sharing less than 80% similarity to other sites and was the only site with virtually no octocoral (<1% cover).

The remaining sites in the left-hand cluster (Figure 4.5) have no defining characteristic. Three of the six groups in this cluster have high (>33%) macroalgae but are separated by other categories. RN9807 and PS2780 have low cover of corals and octocorals, ON5842 and OS12379 have moderate coral but high octocoral cover. RN10105 and RN8924 have high coral and octocoral cover but very little bare sand. Among the other three groups, PS6108 and PS6493 have high cover of corals but have more rock than macroalgae. ON11460 and OS1864 had virtually identical coverage of every benthic category except coral cover, while PN3275 was closely grouped but had slightly less sponge cover. The final group contains the four sites in this cluster with the highest sand cover (ON5527, RN1915, RS10529, OS7675).

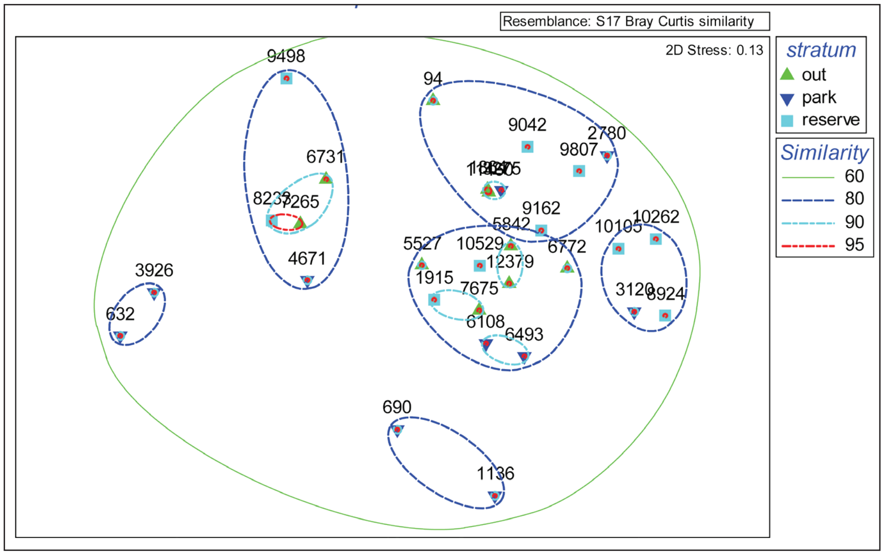

Figure 4.5. Two-dimensional multi-dimensional scaling (MDS) from Bray-Curtis similarities of 2001 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NCCOS CCFHR.

2002-2003

Coral cover was higher at many TER sites than DRTO and unprotected sites in 2002 (Figure 4.6), while in 2003 all TER sites had higher coral cover than sites in other strata (Figure 4.7). As was the case in 2001, RS10262 had the highest coral cover (14.1% in 2002 and 23.5% in 2003). ON11460 was an outlier in the unprotected stratum, with coral cover at 0.1% in 2002 and 0.3% in 2003. Fire coral was commonly observed at the reserve sites (eight and six sites in 2002 and 2003, respectively), but at only two sites did fire coral cover exceed 1% (RN9807 in 2002 and PS2780 in 2003). Black coral was observed at two sites in 2002, both of which were in DRTO. In contrast to 2001, reserve sites generally had the highest octocoral cover in 2002-2003.

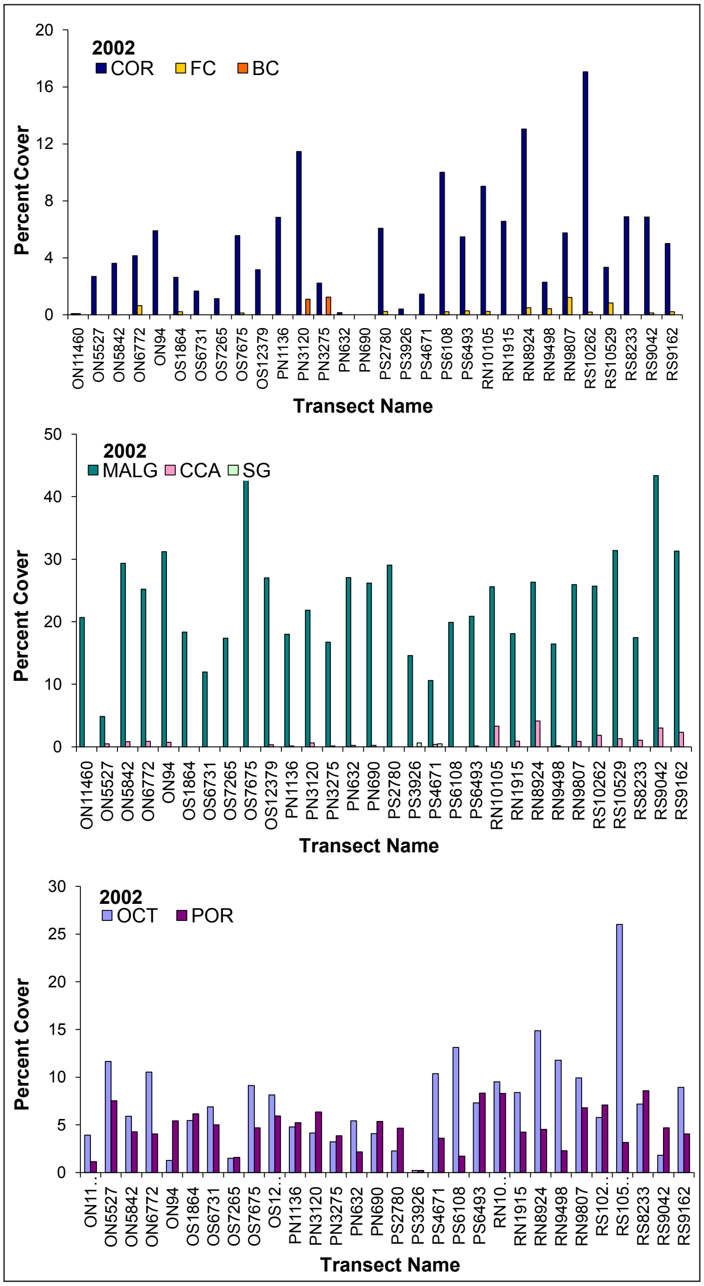

Figure 4.6. Benthic cover of biota on reef transects in 2002. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

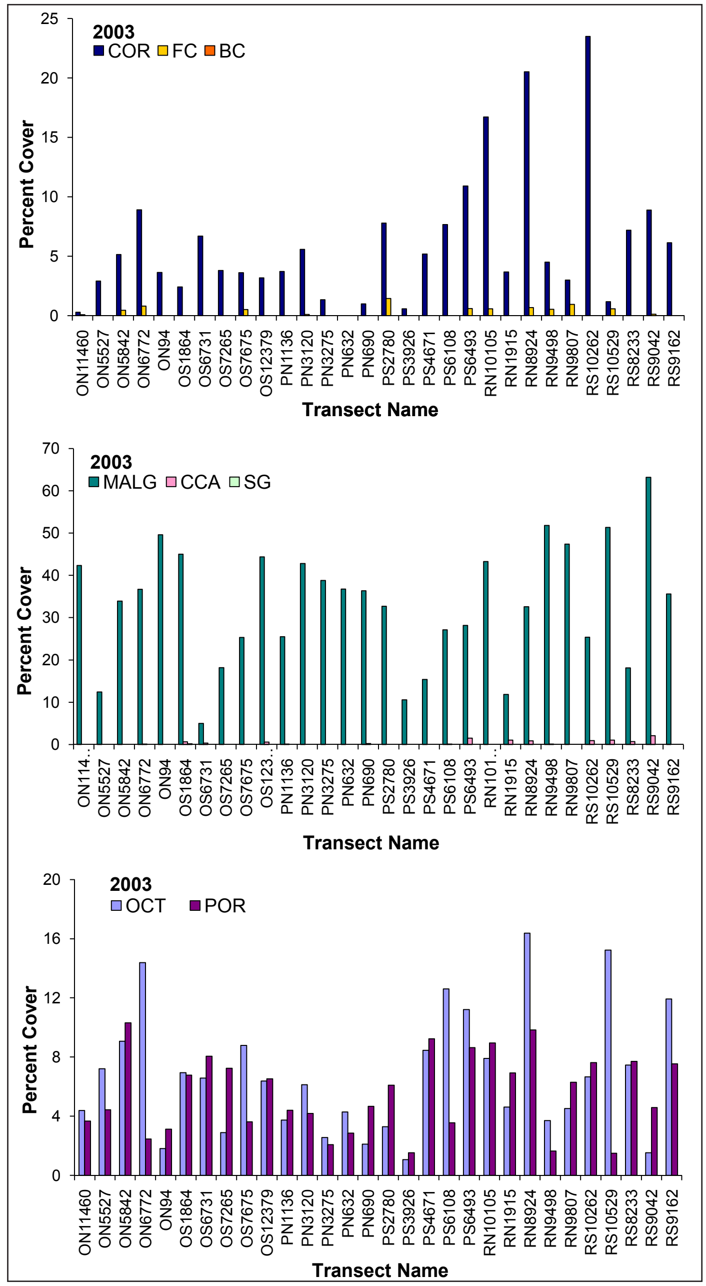

Figure 4.7. Benthic cover of biota on reef transects in 2003. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

Macroalgal cover was highly variable. The unprotected stratum had the site with the lowest macroalgal cover in 2002, but had both the highest and lowest macroalgal sites in 2003. Every TER site in 2002 had CCA, as did seven sites in 2003. Paddle grass seagrass (*Halophila decipiens*) was present at two DRTO sites in 2002, PN3120 and PS4671, but only at OS1864 in 2003. PS3926 again appeared to be the outlier among all sites- macroalgal cover was 14.6% in 2002 and 10.6% in 2003, but no other biological category had cover >1.5%.

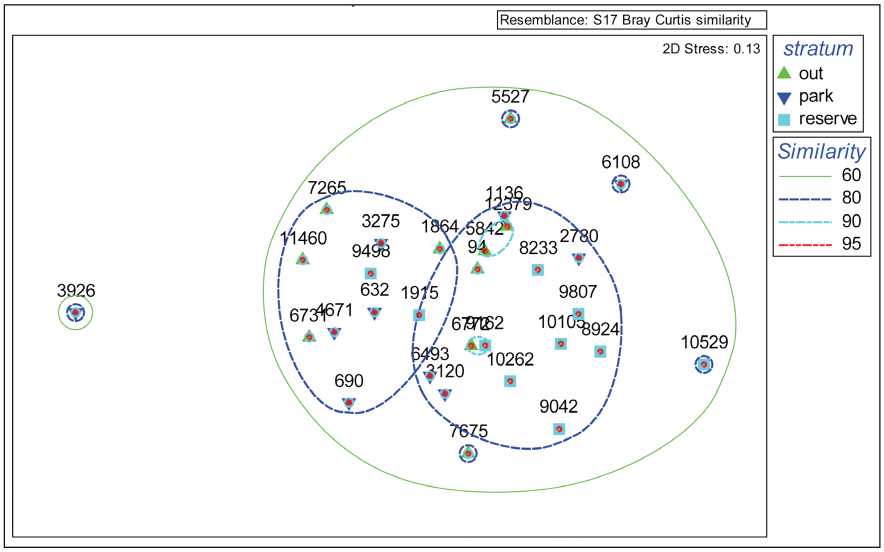

Figure 4.8. Two-dimensional multi-dimensional scaling from Bray-Curtis similarities of 2002 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NOAA CCFHR.

For 2002 data, PCA defined 52.9% of the variation in PC1 with the three dominant functional groups of microalgae and soft substrate, hard substrate and coral. With the addition of macroalgae, PC2 increased the cumulative percent variation explained to 73.9%. For 2003 data, PCA defined 49.3% of variation in PC1 by microalgae and soft substrate macroalgae and coral. The addition of hard substrate increased this to a total of 79.3% variance explained. MDS ordination plots (Figures 4.8 and 4.9) show PS3926 and RS10529 as outliers in both 2002 and 2003. PS3926 is again characterized by very high sand cover and virtually no living biological cover, while RS10529 stands out because it had the highest coverage of zoanthids in each year (5.2% in 2002, 6.1% in 2003). The other two outliers in 2002 were the sites with the highest rock/rubble cover; PS6108 had high coral cover (10%) and moderate macroalgae, while ON5527 had high sponge cover (4.5%). The other 2003 outlier, RS9042, had the highest macroalgal cover that year (63%).

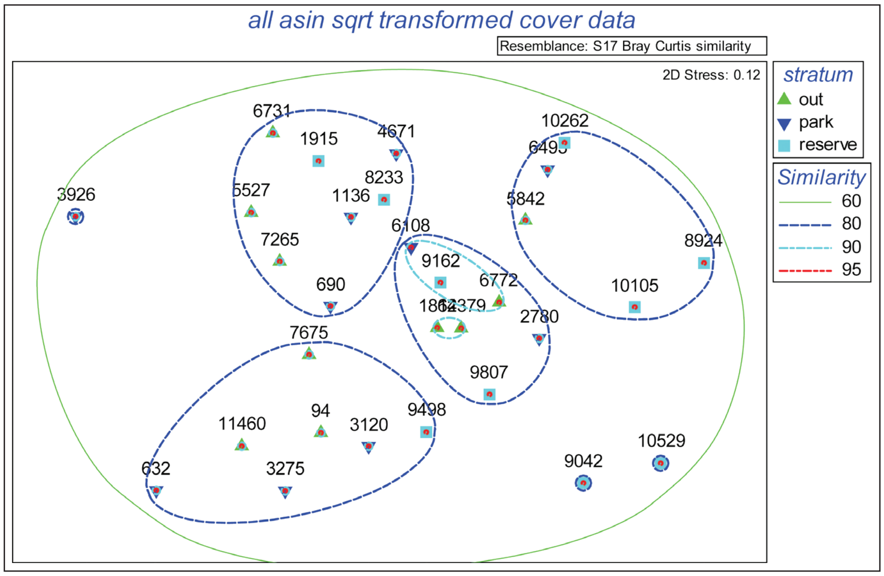

Figure 4.9. Two-dimensional multi-dimensional scaling from Bray-Curtis similarities of 2003 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NCCOS CCFHR.

In 2002 (Figure 4.8) the main cluster on the left has low coral (0.1-2.6%) and high sand (30.5-58%) cover, while the cluster on the right has moderate to high coral cover (3.1-17%). Two sites are members of both clusters—OS1864 has the highest coral cover in the left hand cluster, while RN1915 has the highest sand cover in the right-hand cluster. The groups in the left cluster are characterized by low sponge cover (OS7265 and ON11460), high rock/rubble (OS1864 and PN3275), and high octocoral cover (PS4671 and RN9498). The right-hand cluster has five groups: 3% coral (ON5842, OS12379), low sponge (ON6772, RS9162), high rock (PN1136, OS12379, RS8233), high sand (PS6493, PN3120) and high coral/octocoral (RN10105, RN8924).

Overall clustering patterns differed between 2002 and 2003. The MDS formed three main clusters in 2003 (Figure 4.9). The left cluster contains low (<11.5%) rock/rubble cover, while the right cluster contains sites with very little sand (<5.3%) and high sponge cover (4.6-10.3%). In the right cluster, the two sites with the lowest coral and highest rock cover (PS 6493 and ON5842) group together, while the other three sites have the high-

est coral cover observed in 2003. The middle cluster contains the remainder of the sites and has no coherent organizing characteristics. One group is distinguished by high rock cover (PS4671 and PN1136), while a second has the highest CCA cover in the cluster (RN1915 and RS8233; both are still <1%), OS12379 and OS1864 have essentially identical cover in nearly every category, including the highest amount of unidentified data points (3.2% and 1.8% respectively). The last group (PS6108, RS9162, PS2780, ON6772) has moderate cover of both coral (6.1-8.9%) and macroalgae (24.1-36.7%).

2005

The switch to digital still cameras gave a slightly smaller field of view than was obtained with the video; however, average coral cover for all sites (5.5%) was comparable to previous years (6.0% in 2003, 5.0% in 2002, 6.3% in 2001). Six of the seven sites with the highest coral cover in 2005 were found in TER (Figure 4.10). In all previous years coral was most abundant at RS10262, but in 2005 RN8924 had the highest coral cover (24.5%, the highest observed in any year of this study). Seven of the TER sites had fire coral, including the highest coverage observed in this study (3.7% at RS10529). Black coral was again observed in DRTO (site PN1136) and was rare but present in TER (<0.25% cover at RS10529 and RS8233). There was no apparent pattern in octocoral or sponge cover among sites. Half of the sites had macroalgal cover greater than the highest observed coral cover, compared to 22 sites in each of 2002-2003 and 19 sites in 2001. Paddle grass seagrass was observed at two park sites (PN1136, PS2780), and one TER site (RN1915). CCA was again most commonly observed at TER sites, although the unprotected and DRTO strata each had more sites with CCA than in previous years.

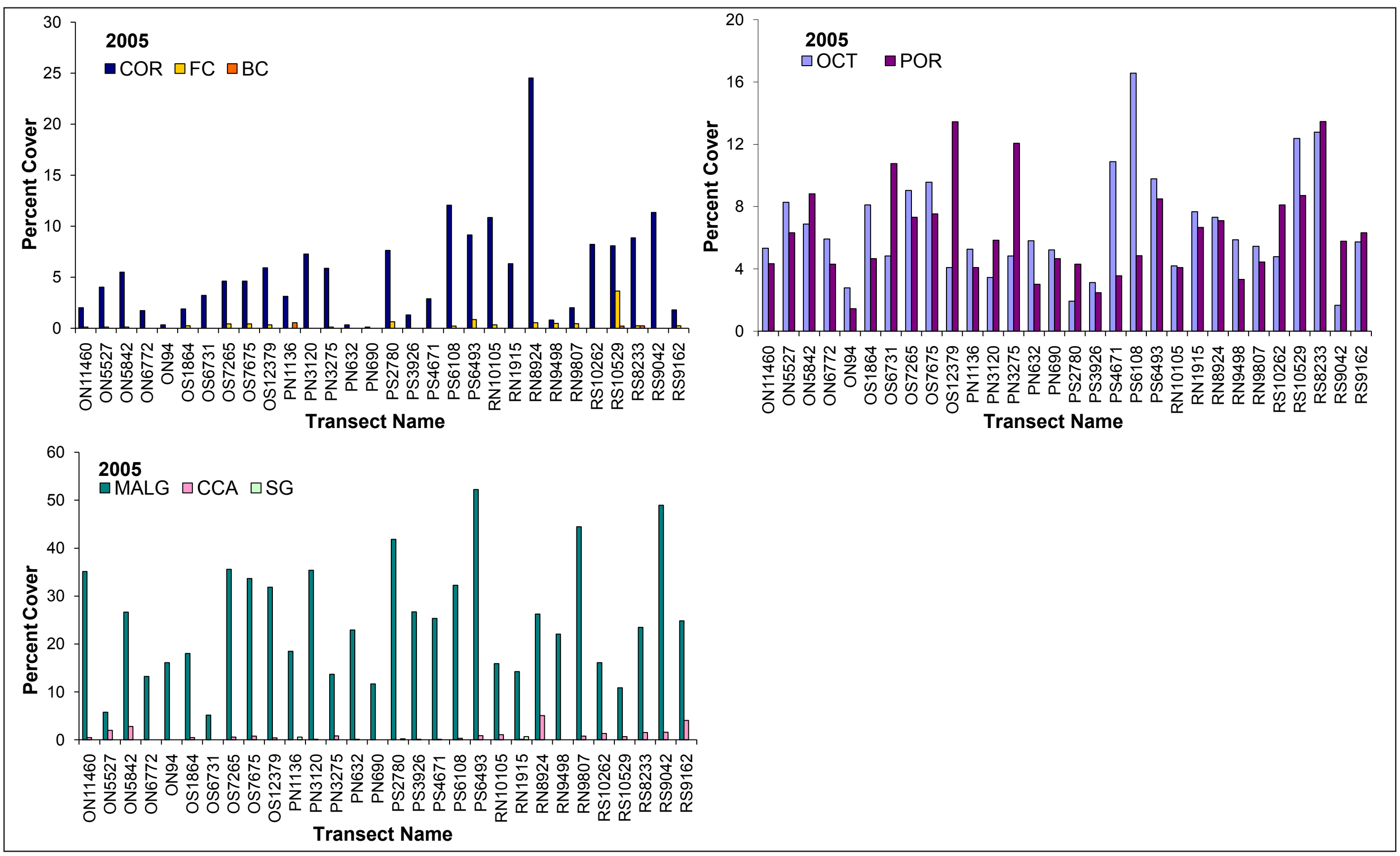

Figure 4.10. Benthic cover of biota on reef transects in 2005. COR = coral, FC = fire coral, BC = black coral, OCT = octocoral, POR = sponges, MALG = macroalgae, CCA = crustose coralline algae, SG = seagrass. Source: NCCOS CCFHR.

For 2005 biotic functional group data, PCA defined 48.0% of the variation in PC1 with the three dominant functional groups of microalgae and soft substrate, macroalgae, and coral. With the addition of hard substrate, PC2 increased the cumulative percent variation explained to 76.2%. In the MDS plot (Figure 4.11), RS10529 is an outlier, as was the case in 2002 and 2003. However, in this case the site is probably isolated as it has far more fire coral than any other site. The other outlier in 2005 was PS2780, which had an unusually high cover of zoanthids.

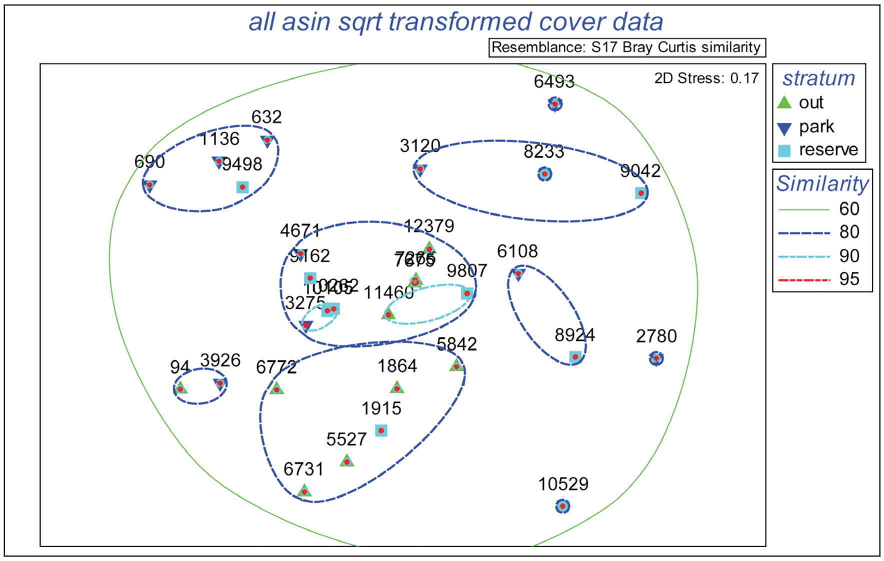

Figure 4.11. Two-dimensional multi-dimensional scaling from Bray-Curtis similarities of 2005 Tortugas coral reef biota functional groups with superimposed group-averaged clustering obtained from the same similarities. Source: NCCOS CCFHR.

The MDS ordination showed three main clusters in 2005. The left cluster contains sites with moderate to high macroalgae (23.5-52.3%). Groups within this cluster include sites with low coral cover (RN9807, ON11460) and low rock/rubble (OS12379, OS7265, OS7675). Sites with high sand cover (54.3-75.7%) form the cluster on the right, with sites grouped by low coral cover (PN1136, RN9498), high coral cover (PN3275, RN10105, RX10262) and high rock/moderate macroalgae (PN632, PS3926). The cluster at the bottom of the plot is intermediate, with low macroalgae (5.2-18%) and moderate sand cover (39.4-58.1%). The two sites with the highest macroalgal cover in this cluster (OS1864, RN1915) grouped together.

OTHER BENTHIC HABITAT STUDIES IN THE DRY TORTUGAS

Many historic benthic habitat studies were conducted in the Dry Tortugas (see Shinn and Jaap, 2005). More recently, there have been several intensive studies using different approaches, methodologies and sites to assess coral reef benthic habitat condition and change.

University of North Carolina Wilmington, University of Miami, Rosenstiel School of Marine and Atmospheric Science and the National Marine Fisheries Service Multi-scale Mapping, Benthic Cover and Fish Surveys

A large-scale assessment of the community structure and condition of hard-bottom and coral reef habitats, coral population structure, and potential habitat change at multiple spatial scales has been conducted since 1999 by the National Undersea Research Center (NURC) at the University of North Carolina Wilmington. This study provides complementary habitat information for fishery-independent reef fish surveys and modeling efforts for evaluating essential fishery habitat (NOAA National Marine Fisheries Service [NMFS] and University of Miami Rosenstiel, School of Marine and Atmospheric Science [UMRSMAS]). The survey design is scaled at three management zones: Tortugas Bank Fished (commercial and recreational fishing), DRTO (recreational hook and line only) and North TER (closed to all fishing since 2001; Ault et al., 2006) as well as by reef, habitat type and regions of the south Florida shelf (Miller et al., 2006).

Independent sample sites were selected randomly from a digital benthic habitat map stratified by nine categories of hard-bottom and coral reef habitat types (Franklin et al., 2003). Each site has four random transects. Surveys use the linear point-intercept method and strip transects to measure coverage, octocoral abundance, species richness, coral size and condition, juvenile coral abundance and size, urchin abundance and size, anemone and corallimorph abundance and algae coverage by functional group (Miller et al., 2000; Miller et al., 2006).

Habitat surveys included 24 sites in 1999, 36 in 2000, 24 in 2002, 46 in 2006, and ranged from 5-27 m depth (Miller et al., 2000; Miller et al., 2006). Physical damage from the 2005 storms was patchy and more apparent on the south side of the park. In 2006, many sites were no longer dominated by gorgonians and sponges. In some high cover areas, coral cover has declined from near 50% in 2004 to approximately 35% in 2006 due to higher amounts of encrusting fan-leaf algae (*Lobophora variegata)* and coral disease (Miller et al., 2006). Stony coral cover means ranged from 0.25% to 31% among 42 of the 46 sites. Sponge species richness was greater than or equal to combined stony corals and gorgonian species richness. Juvenile corals ranged from 0.16/m^2 to 5.77/m^2, with higher densities within DRTO high-relief habitats. These results are similar to the 1999-2000 Tortugas surveys as well as other Florida Keys surveys. Disease prevalence was relatively low (<5%), but some medium-profile reefs and patchy hard-bottom habitat sites on the northern and northeastern areas had higher incidence of disease (15-37%). No bleaching was observed in 2006 (Miller et al., 2006).

Florida Fish and Wildlife Research Institute Long-term Permanent Monitoring for Coral Cover

The state of Florida has a history of research in the Dry Tortugas since 1975. The current Coral Reef Evaluation and Monitoring Project (CREMP) goal is to assess regional coral reef ecological status and trends by annual resource monitoring using repetitive underwater video transects and station species inventories, which includes information on species richness, distribution, and mean percent cover of stony corals and selected functional groups.

Three Dry Tortugas sites (12 stations) were established in 1999, of which two are inside DRTO and one is now within the Florida Keys National Marine Sanctuary (FKNMS) TER. Four additional park sites were added in 2004 (Wheaton et al., 2007). Sites range in depth from 2-12.5 m, and each site has two to four stations marked with permanent markers at start and end points for 22 m long transects. Repeated video transects and species inventories were used to estimate the biodiversity, distribution, coverage, and species richness of stony corals and octocorals, clionid sponge assessment, selected disease conditions, benthic algae coverage and long-spined sea urchin (*Diadema antillarum)* incidence (Wheaton et al., 2007). Similarities between sites and stations were analyzed using MDS of Bray-Curtis similarity indices for functional groups, including coral species.

CREMP monitoring shows coral in the Dry Tortugas has been influenced by disease, bleaching, tropical storm and hurricane activity, and unknown factors. In 2005, 29 total stony coral species (*Millepora* and *Scleractinia*) were identified at 23 Tortugas stations, and mean coral cover ranged from 1.6-13.8% (Wheaton et al., 2007). Stony coral cover averaged 7.2% in 2004 and increased to 6.7% in 2005; however this reduction was not statistically significant. Coral species richness decreased significantly at two sites from when the site was established (1999 or 2001) and 2005, which was attributed to tropical storm activity 2003-2005 (Wheaton et al., 2007). Shallow reefs formerly dominated by acroporids have shown a dramatic decline, for example at one staghorn coral dominated site, coral cover declined from 14.4% in 1990 to 9.5% by 1999 (Wheaton et al., 2007). However, *Acropora* populations have historically fluctuated in the Dry Tortugas due to hurricanes, cold water and other factors (Jaap and Lyons, 1989). Macroalgae cover was relatively low, <10.4%, for all sites in 2004 and 2005 (Wheaton et al., 2007). Octocoral cover varied inversely with coral cover (Shinn and Jaap, 2005). CREMP data showed a decline in *M. annularis* spp. complex and *C. natans* cover from 2003 to 2005, which was attributed to an unknown coral disease (Wheaton et al., 2007). In 2005, 18 of 23 stations showed signs of coral disease or bleaching and 18 of 29 inventoried coral species showed bleaching. staghorn coral had a “white” disease at two stations, and an unknown disease affected *M. annularis* complex species and *S. siderea* (Wheaton et al., 2007).

Environmental Protection Agency Long-term Permanent Monitoring: Coral Disease and Bleaching

Monitoring of coral disease and bleaching prevalence in the Dry Tortugas has been conducted by the Environmental Protection Agency (EPA). Three permanent sites were established in the Dry Tortugas (two at Bird Key and one at Loggerhead Key) as part of a larger study with 30 sites throughout the Florida Keys to characterize coral community composition, abundance, age class structure and species survival. Sites were selected randomly from a spatially-balanced grid. A radial arc transect was used for disease and bleaching surveys and coral colony counts (Santavy et al., 2005). In 2005, five stations in the Dry Tortugas were surveyed and estimates of total coral surface area and percent living coral tissue were added to the methodology (Fisher et al., 2006; Fisher et al., 2007).

In 2000, survey sites throughout the Florida Keys and including the Dry Tortugas had less than 13% disease prevalence, while approximately 80% of the reef area had lower than 5% disease prevalence (Fisher et al., 2006). Dry Tortugas stations had a higher total coral surface area than Key West stations, in addition to differences in size distribution, species diversity and the contribution of different species to total coral surface area. In both Key West and the Dry Tortugas, knobby brain coral (*Diploria clivosa)*, mustard hill coral (*Porites astreoides)* and finger coral had a high percentage of live coral, but boulder brain coral and mountainous star coral had a low percentage of live coral. High numbers of small corals were surveyed and an inverse relationship between abundance and size was found (Santavy et al., 2005). Each colony encountered at the five stations had between 76.4-84.1% live coral calculated. At each station, estimates of total coral surface area ranged from 29.0 m^2 to 42.4 m^2 and estimates of living coral surface area ranged from 22.7-32.4 m^2. At 35.7% *D. clivosa* had the greatest total surface area per species and comprised 33.9% of total coral colonies.

SUMMARY AND CONCLUSIONS

Despite differences in methodologies and site depths, the average and range in coral cover in the CCFHR study were consistent with those reported by the other Tortugas monitoring projects over the same time period. Storm damage, evident at relatively shallow CREMP sites between 2003 and 2005 and at NURC sites in 2006, was not evident at CCFHR sites at the most recent August 2005 survey. However, Hurricane Katrina passed through the area less than two weeks later and was followed by other hurricanes and storms. Coral disease and bleaching, while not specifically addressed by CCFHR benthic habitat studies, has not been prevalent during site visits. In general these other studies have shown an overall reduction in percent coral cover in the TER and other areas of the Tortugas region. Whether or not the TER can mitigate observed changes in benthic composition (e.g., loss of corals) remains to be seen.

The intent of CCFHR's research was to characterize resources at the reef-sand interface in the Tortugas and to monitor the effects of implementing TER. On average half of each reef transect was comprised of non-living substrate (rock and sand). Macroalgae were the most common biological component, with an average cover of 25-33% in a given year. Coral cover was 5-6% in each year but was highly variable among sites, ranging from 0-24.5%. Coral cover was consistently higher at sites within the TER compared with DRTO and unprotected sites for all years (see Figure 4.2), but relationships among sites were not consistent over time. Sampling sites were randomly selected using a rigorous statistical approach, but the resultant variability among sites makes it difficult to detect whether or not TER implementation had an effect on benthic composition. The variability could be constrained over time as additional years have been sampled, which may aid in detecting TER effects. However, the fact that the reserve had consistently higher coral cover than DRTO and unprotected sites suggest that reef habitats within TER initially were of better quality than unprotected sites, assuming that higher coral cover is indicative of habitat quality. The CCFHR survey/site methodologies were optimized for fish data collection, and the benthic characterization was intended to identify fine-scale habitat metrics that (1) would help elucidate fish-habitat fish species habitat relationships, (2) could be used as covariates to help explain spatial and temporal patterns in fish assemblages among management strata, and (3) help parse out natural variation in fish assemblages (i.e. that due to habitat differences) from variation due to protection (i.e. TER effect). Chapter 5 provides a characterization of reef fishes among three management strata in the Tortugas region, and describes fish-habitat associations based on fine-scale habitat presented in this chapter.

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Chapter 5: Characterization of Reef and Shelf Nekton Assemblages

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INTRODUCTION AND BACKGROUND

The monitoring studies described in Chapter 3 focused on visual surveys of reef fishes that occurred in hardbottom habitat types to describe the status and trends in populations in the Tortugas Ecological Reserve Study Area (TERSA). Those studies have not characterized or monitored trends in fish assemblages that occurred in non-hardbottom habitats. Many species inhabiting coral reefs and hardbottom substrates also utilize adjacent habitats linking them through their movements. Reefs typically exist within a mosaic of habitat types that are utilized by fishes through daily home range movements and ontogenetic habitat shifts. For example, some species of snappers and grunts move among adjacent habitats through diurnal migrations in which they feed in seagrass beds at night then return to the reefs during the day (Meyer et al., 1983). Other fishes recruit and settle in mangroves and shallow seagrass beds, but later migrate out to reefs in deeper water at more advanced life stages (Parrish, 1989; Nagelkerken and Van der Velde, 2004; Mumby et al., 2006). Non hardbottom substrates (seagrass beds and sand plains) therefore are important to reef fishes, and demographic interactions among and within these habitats represent critical ecological processes that contribute to the overall health of coral reef ecosystems.

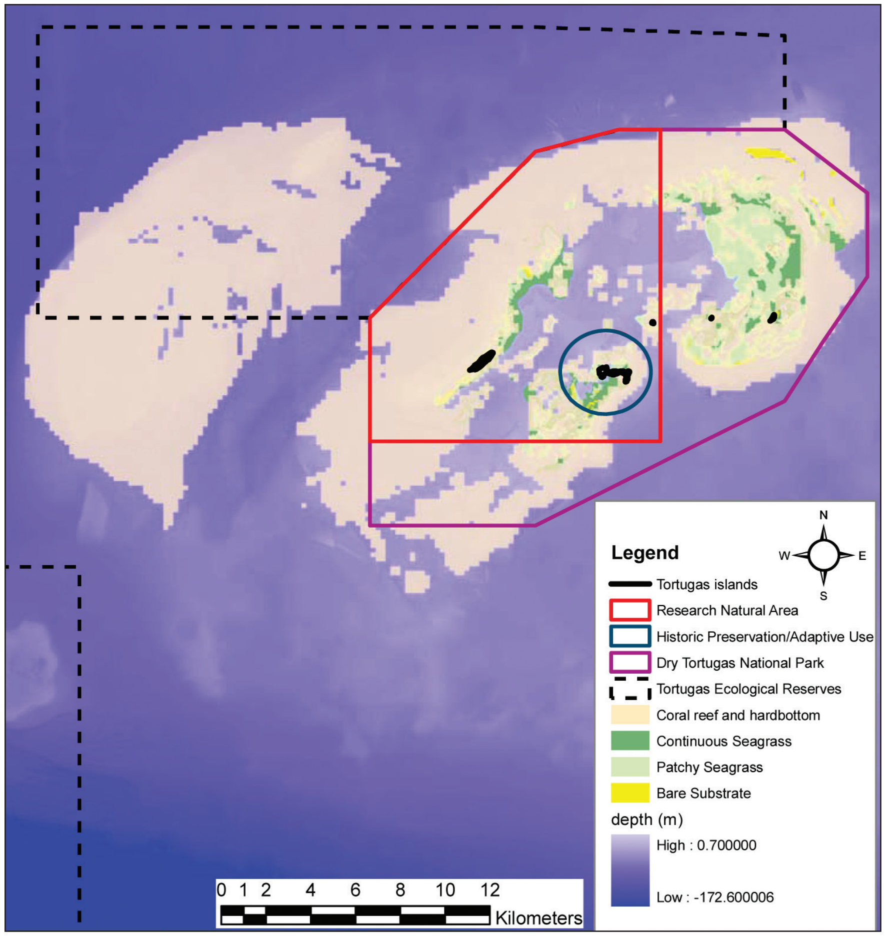

Figure 5.1. Spatial distribution of mapped habitats within the Dry Tortugas National Park (DRTO) and Tortugas Ecological Reserve (TER) North. Source of Data: FMRI, 1998 and Ault et al., 2006.

Coral reefs and hardbottom substrates in the Tortugas region are prominent and extensive benthic features, but the surrounding soft-bottom shelf actually comprises the majority of area enclosed by the boundaries of the Tortugas Ecological Reserve North (TER North; Figure 5.1). In 2001, NOAA's Center for Coastal Fisheries and Habitat Research (CCFHR) began a suite of biogeographic studies to examine the effects of implementing the TER on reef fish assemblages and benthic organisms at reef-sand interfaces (Burke et al., 2004; c.f. Chapter 4). A major premise of the studies is that energy flow across reef-sand boundaries is critical to understanding reef function, and previous work by CCFHR on the west Florida shelf suggests that benthic primary production is the major energetic source supporting regional fish biomass (Currin et al., 2000).

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The following sections summarize results of surveys conducted between 1999 and 2005 as part of long-term studies by NOAA's National Ocean Service and National Marine Fisheries Service (NMFS) investigators from Center for Coastal Fisheries and Habitat Research (CCFHR)on the effects of the TER on reef and shelf nekton in the Tortugas region. Section A characterizes differences in fish assemblage structure at reef-sand interfaces within three management strata to infer TER effects and identify trophic energy flows between sand and reef habitats. Section B presents additional CCFHR studies that: (1) analyze the fish/habitat relationship of the banks and surrounding shelf; (2) Describe sonar surveys of nighttime fish distribution in the TER; (3) described temporal trends in Mutton Snapper (*Lutjanus analis*) spawning aggregations in the TER; (4) identified spatial differences in pink shrimp (*Penaeus duorarum*) abundance among management strata; and (5) characterized trophic structure of reef fish assemblages (as determined by stable isotope analysis) within the TER.

SECTION A. REEF FISH ASSEMBLAGE STRUCTURE AT REEF-SAND INTERFACES

Data Collection and Analysis Methods

To test management effects, an integrated Before-After Control Impact (BACI) design was used. Thirty permanent monitoring sites (Figure 5.2; Appendix II Table A) were randomly selected along the reef-sand interface in 2001 (depth 15-32 m), using the procedures outlined by Burke et al. (2004). Ten sites were established in each of three strata: "Reserve" (within TER), "Park" (in Dry Tortugas National Park, DRTO) and "Open", unprotected areas (several park sites are located within the Research Natural Area (RNA) recently designated within DRTO). Sites within each stratum were equally allocated on either side of the predominant direction of current flow across the banks, resulting in a total of six categories: Park North (PN), Park South (PS), Reserve North (RN), Reserve South (RS), Out North (ON) and Out South (OS). The 30 stations represented not only different management schemes, but also different locations on the bank, exposure to prevailing currents from the northwest, and distance to human occupancy and fishing pressure. Thus, although these potentially confounding variables were not directly measured and included in analyses, they can be considered when interpreting statistical tests of management strata effects.

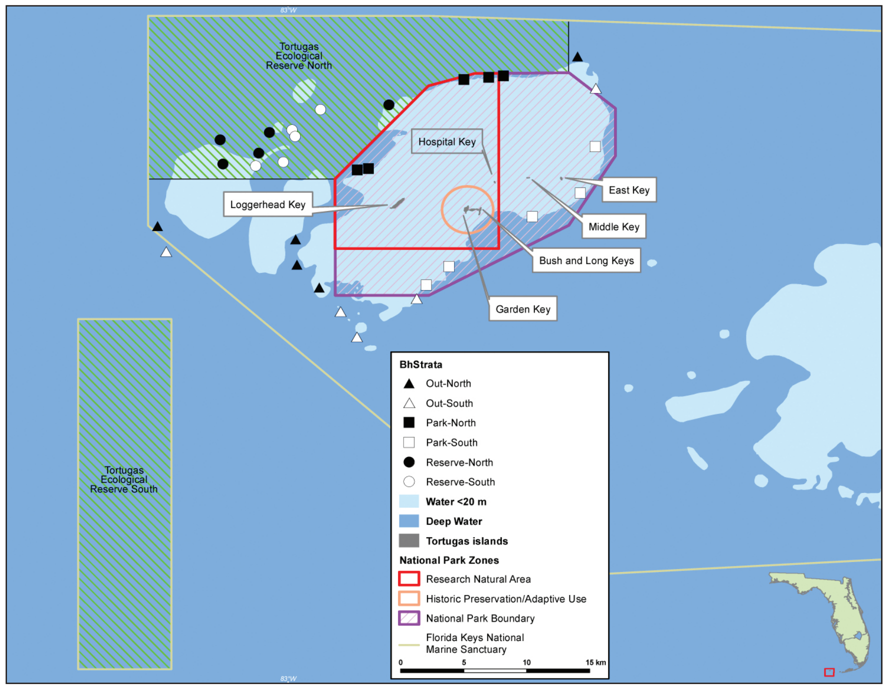


Figure 5.2. Location of permanent reef-sand interface sites in the Dry Tortugas region, the TER and the DRTO surveyed by NOAA Center for Coastal Fisheries and Habitat Research (CCFHR).

Fish and benthic communities were surveyed annually along a 60-m transect perpendicular to the reef-sand interface. The midpoint of the transect occupied the reef-sand interface, with 30 m covering reef habitat and 30 m covering the surrounding sand habitat. Data on fish abundance, size, and species composition were collected and used to describe similarities and differences in reef fish assemblage among sampling strata from 2001 to 2005. More specifically, several metrics were calculated to describe spatial and temporal trends in species abundance, sighting frequencies and assemblage composition and to identify fish-habitat relationships occurring at reef-sand interfaces. With the exception of the fish-habitat association analyses, data from sand and reef habitats were combined and considered one complete survey sample in order to incorporate the potential movement of resources across reef-sand boundaries. Fish-habitat analyses differentiated reef surveys from sand surveys in order to more clearly elucidate species-specific habitat preferences.

A series of univariate and multivariate analyses were conducted using a suite of statistical packages (SPSS© v. 13.0, PRIMER© [v. 5.0, MVSP© [A MultiVariate Statistical Package] v3.1, Systat© [Statistical Analysis and Graphics Software] v11.0, and [Microsoft Excel©]) to identify the factors most likely responsible for observed differences in reef fish assemblages among sites and strata and to explore spatial patterns and temporal trends in reef fish assemblages that occurred at reef-sand interfaces. First rankings of the 25 most abundant and frequently observed species were compared among strata to determine if fish species' ranks were similar or different among management strata. Second, repeated measures Multivariate Analysis of Variance (MANOVA) tests and non-metric dimensional scaling (MDS) ordinations were conducted to determine the relative effects of management strata, current exposure, and time (years) on fish community metrics (species richness, diversity, and total abundance of individuals). Initial analyses showed that, within years and management strata, fish abundance, species, richness, and diversity did not differ significantly between the two current exposures regimes (Student's t test, $p>0.05$). Hence, data were pooled across current exposures to examine spatial differences among management strata within years as well as annual trends within each management stratum. Third, 12 species (hereafter focal species) were selected for detailed analyses to elucidate further the effects of management strata, years, and current exposure on fish abundance (number of individuals per sample), biomass and size-frequency distributions. These focal species were chosen based on abundance and their ecological and commercial importance in the region (Appendix II, Table B). Fourth, stepwise backward regressions and canonical correspondence analysis were conducted to identify correlations and associations between fine-scale (meters) habitat variables (described in Chapter 4) and reef fish metrics (i.e., abundance of focal species and fish community metrics).

Results

Comparisons of Species Rankings Among Management Strata

Table 5.1 lists the 25 most abundant species (based on total abundance) from all five years of surveys. In general, Masked Gobies (*Coryphopterus personatus*), Purple Reeffish (*Chromis scotti*), unidentified grunt species (juveniles), Bluehead Wrasse (*Thalassoma bifasciatum*), Tomtate (*Haemulon aurolineatum*), and Yellowtail Snapper (*Ocyurus chrysurus*) were among the most abundant species, regardless of management strata designation. Among the three different management strata, 16 species were common to all three lists of the 25 most abundant species, suggesting similarity in fish assemblage structure across management boundaries (Table 5.1). However, this similarity appears valid only for non-exploited species (i.e., those not targeted by fishers) that were very abundant. There were slight differences in the occurrence and ranking of exploited species among the management strata.

Five of the 25 most abundant species seen overall were considered "exploited" species or vulnerable to fishing pressure (Table 5.1). Among the 25 most abundant fish species, six exploited species were observed in both the Out and the Park strata and five exploited species were observed in the Reserve stratum. Of the 25 most abundant species, five species were unique to stations in Out and Park strata, whereas only one species was unique to stations in the Reserve stratum (Table 5.1).

Rankings of species by sighting frequencies also revealed some similarities and differences in fish assemblages across management strata (Table 5.2). Sixteen of the 25 most frequently observed species were common to the lists of most frequently sighted fish from the three different management strata. However, the differences in rank order based on sighting frequencies indicate there was some variability in the composition of fish assemblages among the management strata. Six exploited species were among the 25 most frequently seen species across all stations across management strata (Table 5.2). Two additional exploited species (Scamp, *Mycteroperca phenax*, and Tomtate) ranked among the 25 most frequently observed species at Park stations but were not ranked in the top 25 species at Reserve or Out stations (Table 5.2). Five of the 25 most frequently observed at Park stations were unique to that stratum and included two exploited species – Scamp and Tomtate (Table 5.2).

Table 5.1. The 25 most abundant species, in descending order of abundance at all stations and within each management strata. Ranks are based on total abundances of each species at all relevant stations for all five years of sampling. A period indicates that the species did not occur among the top 25 most abundant species within the strata. Shaded cells indicate occurrence of exploited fish species within strata. **Bold** *text indicates species that were among the top 25 most abundant in all three management strata. Scientific names of species are provided in Appendix II, Table B.*

Species Common Name	Rank Within Strata			
	All Stations	Out Stations	Park Stations	Reserve Stations
Masked Goby	**1**	**1**	**1**	**1**
Purple Reeffish	**2**	**4**	**3**	**2**
grunt species	**3**	**3**	**2**	**3**
Bluehead Wrasse	**4**	**2**	**7**	**4**
Tomtate	**5**	**5**	**4**	**6**
Yellowtail Snapper	**6**	**11**	**5**	**5**
Blue Chromis	7	6	.	19
Striped Parrotfish	**8**	**9**	**6**	**8**
Slippery Dick	**9**	**7**	**12**	**9**
Yellowtail Reeffish	10	.	9	7
Blue Goby	**11**	**12**	**8**	**15**
Bicolor Damselfish	**12**	**8**	**16**	**10**
Cocoa Damselfish	**13**	**15**	**11**	**12**
Yellowhead Wrasse	**14**	**10**	**18**	**13**
Yellowhead Jawfish	**15**	**13**	**13**	**25**
White Grunt	**16**	**22**	**10**	**18**
Striped Grunt	**17**	**21**	**14**	**23**
Brown Chromis	18	16	.	24
French Grunt	**19**	**25**	**20**	**14**
Silversides	20	24	.	11
Creole Wrasse	21	14	.	.
Blue Tang	22	.	23	17
Bar Jack	23	.	.	16
Spotted Goatfish	24	.	22	.
Threespot Damselfish	25	.	.	20
goby species	.	17	.	.
Bluestriped Grunt	.	18	.	.
Princess Parrotfish	.	19	.	.
Blue Parrotfish	.	20	.	.
Beaugregory	.	23	.	.
Gray Snapper	.	.	15	.
Sand Perch	.	.	17	.
Butter Hamlet	.	.	19	.
Bridled Goby	.	.	21	.
Chalk Bass	.	.	24	.
Redband Parrotfish	.	.	25	21
Goldspot Goby	.	.	.	22

Table 5.2. The 25 most observed species, in descending order of sighting frequency at all stations and within each management strata. Ranks are based on sighting frequency of each species at all relevant stations for all five years of sampling. A period indicates that the species did not occur among the top 25 most frequently observed species within the strata. Shaded cells indicate occurrence of exploited fish species within strata. **Bold** *text indicates species that were among the top 25 most frequently seen in all three management strata. Scientific names of species are provided in Appendix II, Table B.*

Species Common Name	All Stations		Out Stations		Park Stations		Reserve Stations	
	Rank	%SF	Rank	%SF	Rank	%SF	Rank	%SF
Bluehead Wrasse	**1**	**89**	**1**	**92**	**2**	**78**	**1**	**96**
Striped Parrotfish	**2**	**81**	**3**	**78**	**1**	**80**	**3**	**84**
Purple Reeffish	**3**	**77**	**5**	**70**	**3**	**76**	**2**	**86**
Yellowtail Snapper	**4**	**70**	**8**	**62**	**5**	**66**	**4**	**82**
Cocoa Damselfish	**5**	**69**	**7**	**66**	**4**	**74**	**10**	**66**
Masked Goby	**6**	**67**	**10**	**60**	**6**	**66**	**5**	**76**
Bicolor Damselfish	**7**	**65**	**2**	**80**	**19**	**40**	**6**	**74**
Slippery Dick	**8**	**64**	**4**	**76**	**8**	**62**	**15**	**54**
Butter Hamlet	**9**	**63**	**9**	**62**	**7**	**64**	**11**	**62**
Yellowhead Wrasse	**10**	**61**	**6**	**68**	**17**	**42**	**7**	**72**
Blue Angelfish	**11**	**55**	**15**	**48**	**12**	**48**	**9**	**70**
Blue Tang	**12**	**55**	**11**	**52**	**18**	**42**	**8**	**72**
Red Grouper	**13**	**55**	**13**	**50**	**9**	**58**	**14**	**58**
White Grunt	**14**	**53**	**14**	**50**	**13**	**48**	**13**	**60**
Redband Parrotfish	**15**	**50**	**19**	**42**	**14**	**46**	**12**	**62**
Hogfish	**16**	**46**	**21**	**38**	**11**	**50**	**16**	**50**
Spotted Goatfish	17	43	12	52	.	28	17	48
Blue Goby	18	42	18	44	10	52	.	30
Gray Angelfish	19	37	.	26	21	36	18	48
Tobaccofish	20	36	20	42	20	40	.	26
Yellowtail Reeffish	21	35	.	24	15	46	24	34
Foureye Butterflyfish	22	34	16	48	.	16	21	38
Spotfin Butterflyfish	23	33	.	28	.	28	19	42
Threespot Damselfish	24	33	.	28	.	28	20	42
Yellowhead Jawfish	25	32	22	36	22	34	.	26
Stoplight Parrotfish	26	31	23	34	.	22	22	38
Blue Hamlet	27	29	.	26	.	28	25	34
Black Grouper	28	29	.	20	16	44	.	22
Reef Butterflyfish	29	29	17	46	.	26	.	14
Porkfish	31	25	.	20	.	20	23	36
Saucereye Porgy	34	24	24	32	.	22	.	18
Tomtate	35	24	.	24	24	32	.	16
Princess Parrotfish	40	22	25	30	.	16	.	20
Queen Angelfish	41	22	.	28	.	20	.	18
Sharpnose Puffer	42	21	.	24	.	28	.	12
Blue Chromis	43	21	.	28	.	8	.	26
Scamp	48	17	.	12	23	34	.	6

Spatial and Temporal Variation in Fish Assemblage Metrics

Abundance

Mean total abundance varied significantly among years (F=17.16, df=4, p<0.001) and management strata (F=4.15, df=2, p=0.03). Within years, differences in abundance among management strata were significant in 2001, such that sites in the Out and Reserve strata were significantly higher in abundance than sites in the Park strata (F=7.58, p=0.001). Significant among-stratum differences were not observed after 2002 (p>0.05, Figure 5.3A). By 2005, total abundance was highest in the Reserve stratum, followed by the Park stratum and Out stratum.

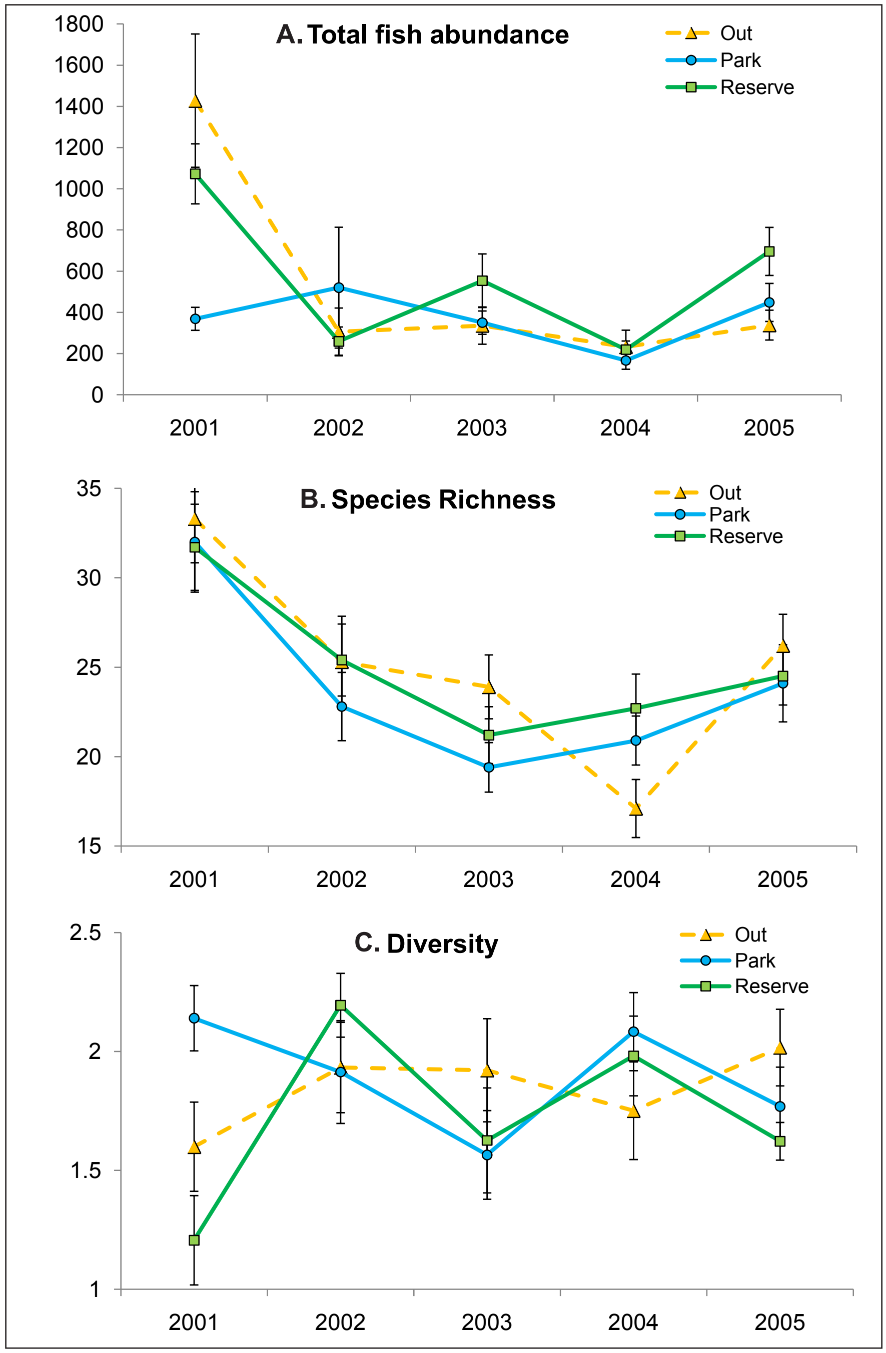


Figure 5.3a-c. Mean and standard error (S.E.) values of fish assemblage metrics by management strata over the five year sampling period spanning 2001-2005: (A) total fish abundance, (B) species richness and (C) diversity.

Species Richness

For all strata, estimates of species richness generally decreased through time from 2001 to 2003, and then increased (Figure 5.3B). Variation in species richness was greatest for the Out stratum, with highest richness occurring in 2001 and lowest richness occurring in 2004. Differences in species richness among stratum were not statistically significant (p=0.345).

Diversity

Fish species diversity varied similarly among management strata with no increasing or decreasing trend (Figure 5.3C). Significant differences among management stratum were observed in 2001 (F=5.23, p=0.012) but not during other years. Significant differences in diversity were observed among years at reserve sites, with 2002 and 2004 having more diverse reef fish assemblages than other years (q*=2.84145, p<0.05, Tukey-Kramer multiple comparison HSD test). Though a temporal trend in diversity was not apparent in any management strata during the period, after 2002 diversity within the reserve and park appeared positively correlated and negatively correlated to diversity in the open strata (Figure 5.3C).

Reef and Shelf Nekton Assemblages

Community Composition

Spatio-temporal community patterns based on the presence and abundance patterns of all fish species were evaluated using Analysis of Similarities (ANOSIM) in Primer (Table 5.3). Data were fourth-root transformed to ensure that species that occurred in very high abundances (e.g., Masked Gobies and Bluehead Wrasse) did not swamp patterns of other species which naturally occur in smaller numbers.

For a given factor, the Global R statistic represents the degree of similarity among samples of the same factor level versus samples from different factor levels. Thus, as Global R value increases, there is better segregation among factor levels. Based on this, station and year factors seem to be more strongly segregating than do management strata or current exposure factors, yet all four factors have fairly low, but significant, Global R values (Table 5.3). However, a MDS plot of the 150 unique samples (representing unique station-year combinations) arranged in two-dimensional space show no clear segregation of stations by year, management strata, or current-exposure as would be expected if presence and abundance of fish species were significantly different among these factors (Figure 5.4). A MDS plot of presence and abundance of fish species, averaged across all years for each station suggest that stations within the park tended to differ from out and reserve stations. Reserve and open strata stations were strongly clustered compared to park stations, five of which were segregated from and four on the margin of the cluster of reserve and open stations (Figure 5.5).

Table 5.3. Results of Analysis of Similarities (ANOSIM) analyses for significant effects of each factor on fish community patterns. Each station-year sample is considered an independent sample, for a total sample size of 150.

Factor	Global R	Significance
Station	0.344	<0.1%
Year	0.153	<0.1%
Strata	0.09	<0.1%
Current Exposure	0.051	<0.1%

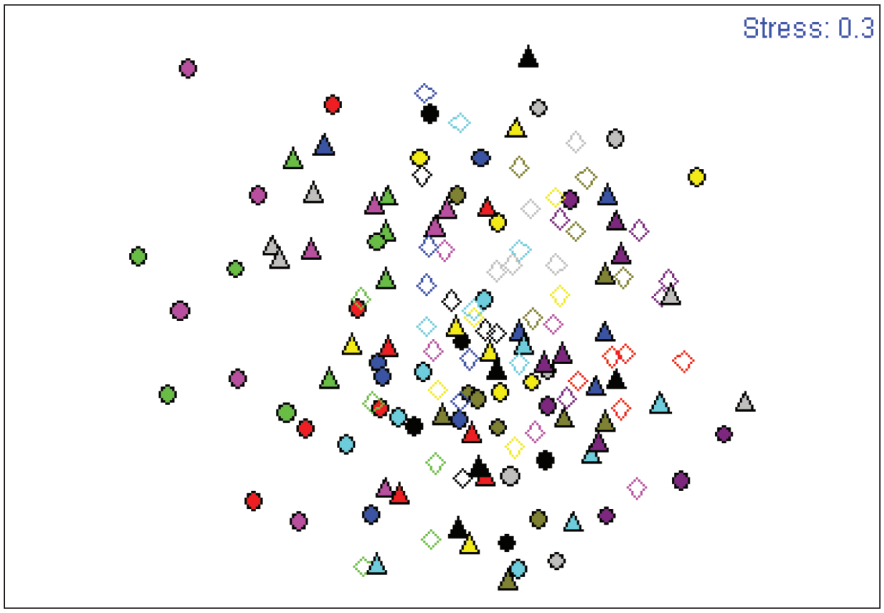


Figure 5.4. Two-dimensional multidimensional scaling (MDS) plot of all 150 samples. Shaded triangles represent Out stations, shaded circles represent Park stations, and open diamonds represent Reserve stations. Each unique color/symbol combination represents a different station.

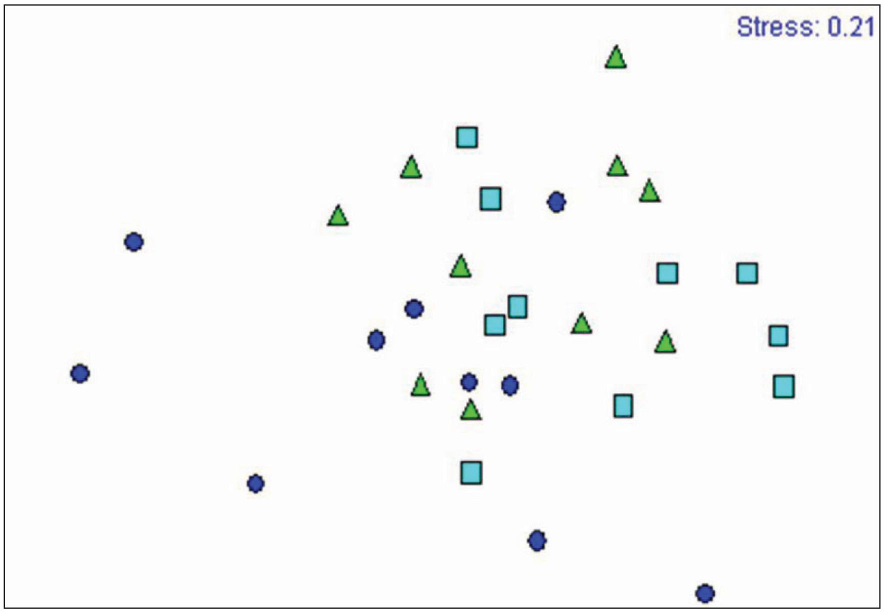


Figure 5.5. Two-dimensional MDS plot of 30 averaged station points. Each symbol represents one station averaged over the five years of sampling. Triangles represent Out stations, circles represent Park stations, and squares represent Reserve stations.

Analysis of Patterns of 12 Selected Focal Species

Mean abundances and standard errors (± S.E.) are presented in Table 5.4 for 12 focal species that were selected for further detailed analyses. This particular suite of species was chosen so that common and/or abundant species, as well as a variety of trophic levels and extents of exploitation, were represented. The Bluehead Wrasse was the most frequently observed species across all stations (Table 5.2). It is an invertivore that feeds mainly on zooplankton, small benthic animals, and ectoparasites of other fishes (Froese and Pauly, 2006) and was selected because it is an often used species for ecological studies. The Coco Damselfish (*Stegastes variablis*) was the most frequently observed damselfish species across all stations (Table 5.2) and was selected to represent damselfishes which are numerically dominant and functionally important herbivores in coral reef ecosystems (Choat, 1991). The other ten species listed in Table 5.4 are species that are targeted by commercial fisheries in Florida (groupers, Hogfish, Yellowtail Snapper) and the Caribbean.

Table 5.4. Mean abundances (and standard errors, S.E.) per sample for each of the 12 focal species. Means were calculated for all stations, as well as for each different management stratum.

Species	All Stations		Out Stations		Park Stations		Reserve Stations	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Bar Jack	2.89	0.91	2.00	0.76	1.70	0.84	4.73	2.34
Black Grouper	0.57	0.08	0.60	0.17	0.53	0.10	0.60	0.16
Bluehead Wrasse	17.01	1.94	14.52	1.90	7.88	2.23	28.54	4.52
Bluestriped Grunt	4.24	2.45	7.85	5.45	1.20	1.20	1.40	0.49
Cocoa Damselfish	4.09	0.60	4.20	1.33	3.96	0.73	4.12	0.96
Hogfish	0.70	0.07	0.52	0.13	0.68	0.12	0.93	0.14
Red Grouper	0.81	0.07	0.80	0.13	0.89	0.14	0.76	0.11
Spotted Goatfish	1.63	0.24	1.52	0.34	1.57	0.51	1.80	0.42
Stoplight Parrotfish	0.74	0.12	0.76	0.21	0.57	0.18	0.85	0.21
Striped Parrotfish	8.67	0.97	7.80	1.35	9.64	2.33	8.58	1.16
White Grunt	3.58	0.70	2.89	0.61	5.27	1.93	2.68	0.70
Yellowtail Snapper	10.74	1.53	6.50	1.86	11.48	3.14	14.31	2.74

The effects of year, management strata, and current exposure on the abundance of each species (number of individuals observed per sample) were examined using non-parametric Kruskal-Wallis tests. Overall, White Grunt (*Haemulon plumierii*) and Yellowtail Snapper were the only two of twelve selected species whose abundance varied significantly among years ($p<0.004$). Mean White Grunt abundances were less than four individuals per transect between 2001 and 2003 for all management strata but quadrupled to about 16 individuals per transect in 2004 at sites in the Park stratum (Figure 5.6). Similarly, mean abundance of Yellowtail Snapper was less than 15 individuals per transect for years 2001 through 2004 for all management strata, but in 2005, it increased drastically to 32 individuals per transect at Park sites and to 77 individuals per transect at Reserve sites (Figure 5.7).

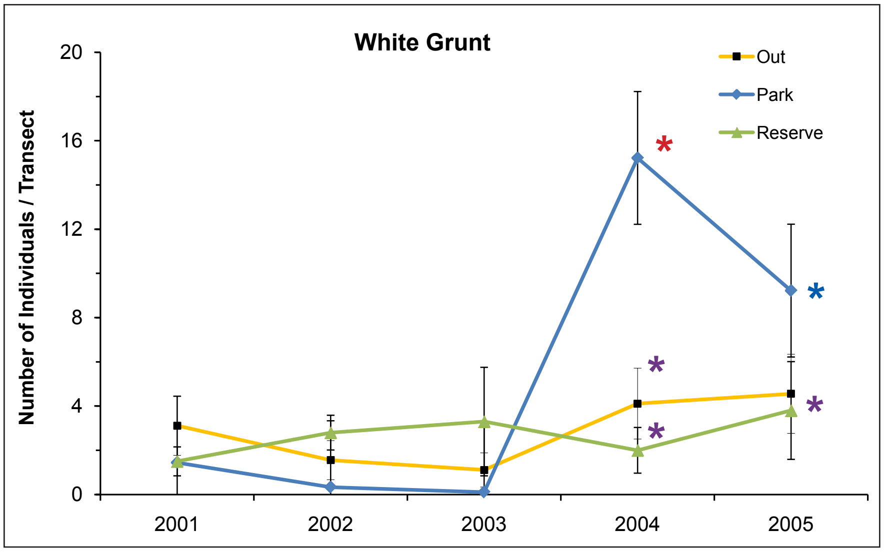


*Figure 5.6. Mean S.E values of White Grunt (*Haemulon plumierii*) abundance by management strata over the five year sampling period spanning 2001-2005. An asterisk (*) indicates year is significantly different from other years within a given management stratum ($p<0.004$, Bonferonni corrected Kruskal-Wallis tests; $p>0.004$ for differences among management strata within a given year; N=150).*

The Yellowtail Snapper can be expected to represent an excellent indicator species for fisheries management impact in the region. Yellowtail snapper, is the most important reef fish species in terms of income to the fishermen of the Florida Keys (Waters et al., 1993) and its landing were approximately an order of magnitude higher than any other species harvested commercially from the Tortugas during the survey period (Florida Fish and Wildlife Commission data).

Bluehead Wrasse was the only species analyzed whose mean abundance showed differences among management strata; however, differences among years within each stratum were not significant ($p>0.004$). Within years, annual mean abundances of Bluehead Wrasse were highest at Reserve sites followed by Out sites, with Park sites having the lowest means ($\Pi^2=33.7$, $p=0.001$; Figure 5.8). Current exposure had no statistically significant effect on the abundance patterns of any species analyzed.

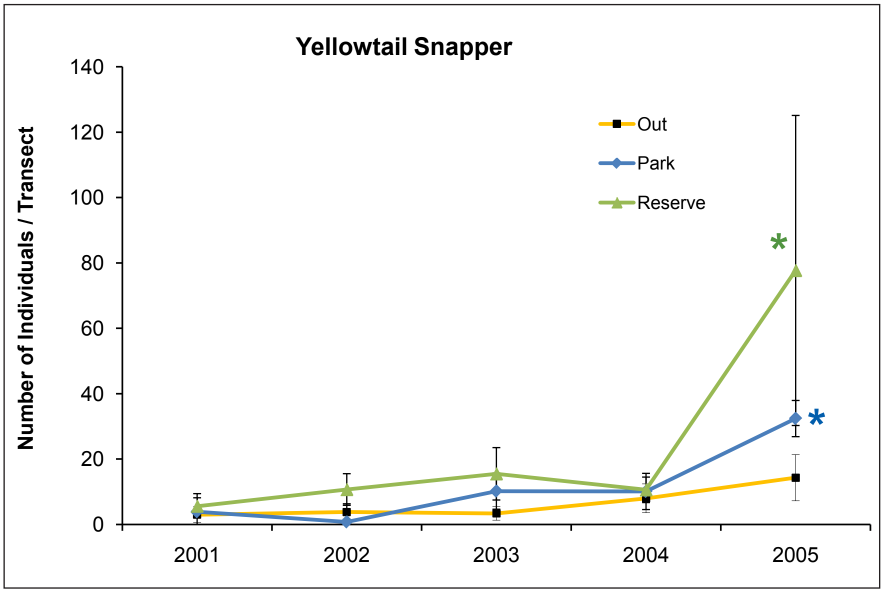


*Figure 5.7. Mean S.E. values of Yellowtail Snapper (*Ocyurus chrysurus*) abundance by management strata over the five year sampling period spanning 2001-2005. An asterisks (*) indicates year is significantly different from other years within a given management stratum (p<0.004, Bonferonni corrected Kruskal-Wallis tests; p>0.004 for differences among management strata within a given year; N = 150).*

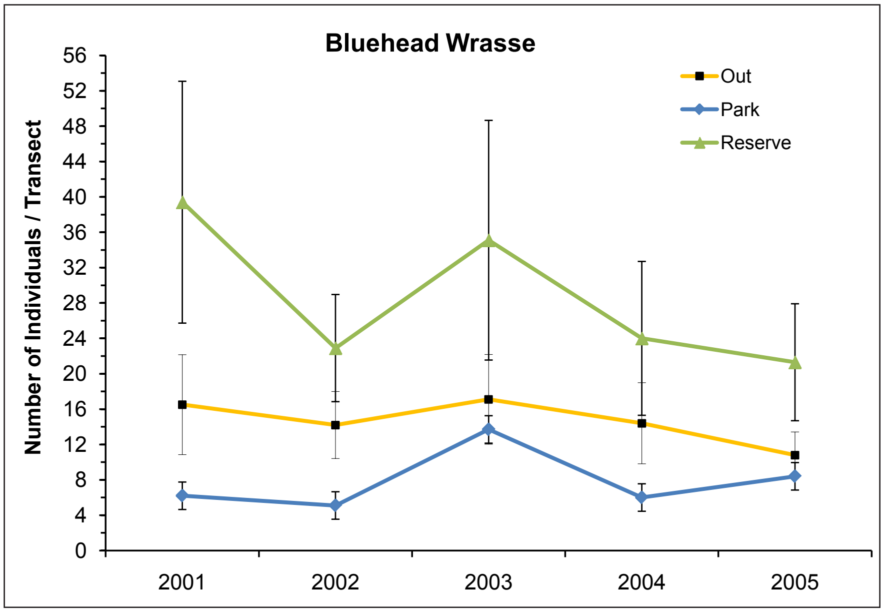


*Figure 5.8. Mean S.E. values of Bluehead Wrasse (*Thalassoma Bifasciatum*) abundance by management strata over the five year sampling period spanning 2001-2005. Colors also indicate significant differences among management strata (p<0.004, Bonferonni corrected Kruskal-Wallis tests; p>0.004 for differences among years within strata; N=150).*

Bonferroni corrected Kruskal-Wallis Tests were used to determine if size-frequency distributions of the 12 selected species varied significantly by year or management strata. Fish sizes were estimated as the mid-points of the size-classes to which each individual fish was assigned. Whereas test of the total abundance of the 12 selected species only showed significant temporal variation for White Grunt and Yellowtail Snapper, size of three small reef fish often abundant on reefs-- Bluehead Wrasse Cocoa Damselfish and Striped Parrotfish-- varied significantly relative to year. Length of Cocoa Damselfish also varied significantly among management strata, tending to be larger in the park than other management zones (Figure 5.9). Significant variation in size among management strata was also evident for Yellowtail Snapper which tended to be larger in the reserve than in the Out sites (Figure 5.10). These differences among species in size class trends,at least in part, may be due to recruitment variability, variable fishing pressure and variable resource availability over space and time.

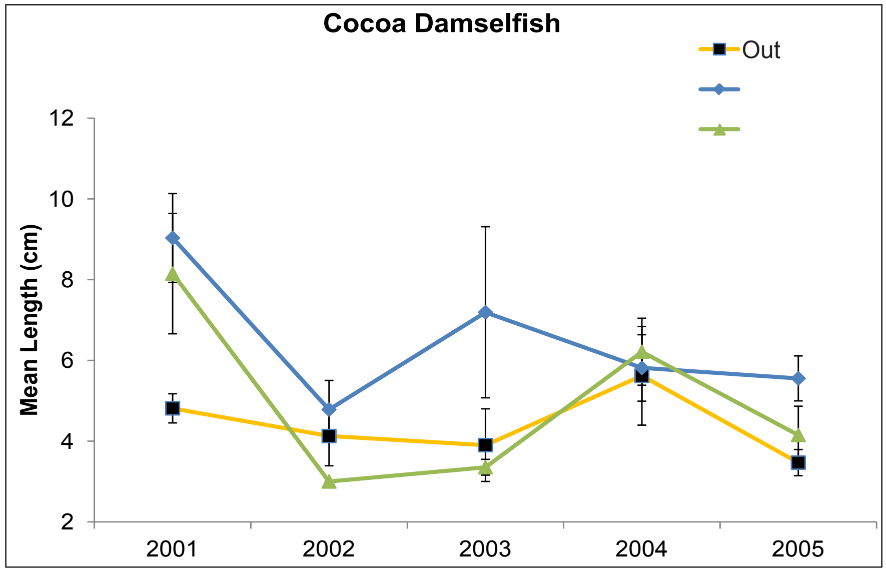


Figure 5.9. Mean length (±S.E) of Cocoa Damselfish by management strata over the five year sampling period spanning 2001-2005. A significant difference in mean length was detected among management stratum (p<0.02, Bonferonni corrected Kruskal-Wallis test).

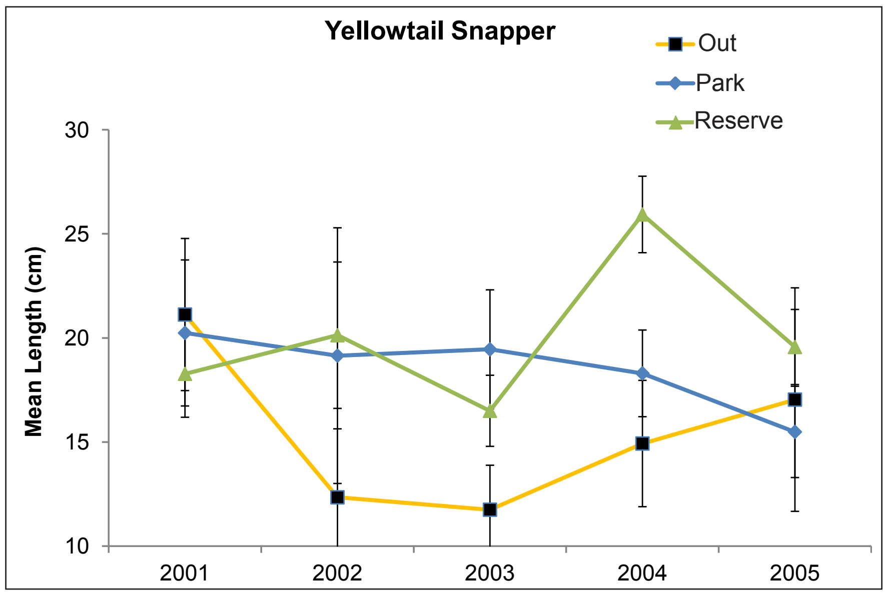


Figure 5.10. Mean length (±S.E) of Yellowtail Snapper by management strata over the five year sampling period spanning 2001-2005. A significant difference in mean length was detected among management stratum (p< 0.02, Bonferonni corrected Kruskal-Wallis test).

Although not conclusive, these differences in size over time and among management strata suggest that different species do not necessarily respond similarly to the same management actions and/or environmental conditions. Differing responses from different species may be at least partially a result of differences in life histories, trophic patterns, and habitat use patterns, and thus these differences must be considered when planning for multi-species management efforts.

For each species, the total biomass (in kilograms, from all 150 samples combined) and average individual biomass (grams) are listed in Table 5.5. Biomass values were computed according to the length-weight relationship W=a*Lb, with a and b values obtained from www.Fishbase.org (Froese and Pauly, 2006). Since a and b values vary for each species with geographic location and fish length, the species' values which matched both the size range and geographic area of each individual fish were selected, whenever possible. If values that matched both size and geographic area were not available for a particular species, then the most acceptable values were used (i.e., matching size range and a close geographic area). Kruskal-Wallis tests were also used to examine if the total biomass of each species varied among years, management strata, or current exposure orientations.

Table 5.5. Total biomass values and mean individual biomasses for each species at all stations and among the different management strata. Total biomass for each species was calculated as the sum of biomass estimates for individuals within species.

Species	N	Total biomass (kg)	All Stations		Out Stations		Park Stations		Reserve Stations	
			Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Bar Jack	251	79.7	316.2	19.6	312.3	22.7	222.2	30.4	343.7	15.9
Black Grouper	57	65.5	1149.5	223.3	1310.2	49.1	1001.7	38.8	1212.7	44.8
Bluehead Wrasse	4684	17.6	3.8	0.1	3.1	3.7	4.9	9.2	4.5	4.7
Bluestriped Grunt	191	11.3	59.3	11.1	12.6	15.2	757.5	77.6	171.7	35.9
Cocoa Damselfish	700	4.1	5.8	0.4	5.3	11.7	8.9	12.5	3.0	13.2
Hogfish	108	79.7	745.1	88.5	489.7	34.7	719.2	32.1	949.1	29.3
Red Grouper	117	67.0	572.9	37.6	681.2	30.8	508.2	29.7	534.4	30.8
Spotted Goatfish	254	10.3	40.7	4.2	39.8	17.9	30.5	24.9	49.0	20.9
Stoplight Parrotfish	85	16.0	188.5	21.4	140.5	32.6	197.9	46.1	231.8	32.6
Striped Parrotfish	1332	19.7	14.8	1.2	16.3	9.5	12.7	8.5	15.8	9.1
White Grunt	504	97.7	193.8	9.4	251.1	16.7	144.6	12.3	226.5	16.4
Yellowtail Snapper	2149	300.6	139.9	3.6	154.6	10.0	131.4	7.9	139.6	5.5

Only three of the 12 focal species showed significant variation in biomass among years or management strata ($p<0.004$, Bonferonni corrected Kruskal-Wallis tests). None of the selected species showed any significant variation in biomass across the two current exposure strata ($p>0.004$). In 2001, mean biomass of Bluehead Wrasse, a non exploited species, was lower at sites in the reserve compared with sites in the outside stratum, but by 2004, sites in the reserve had higher mean biomass of Bluehead Wrasse than sites outside (Figure 5.11). Similarly, Park sites had lower mean biomass of Bluehead Wrasse than sites in the outside stratum, but by 2005, Park sites had higher Bluehead Wrasse biomass than sites in the outside stratum (Figure 5.11).

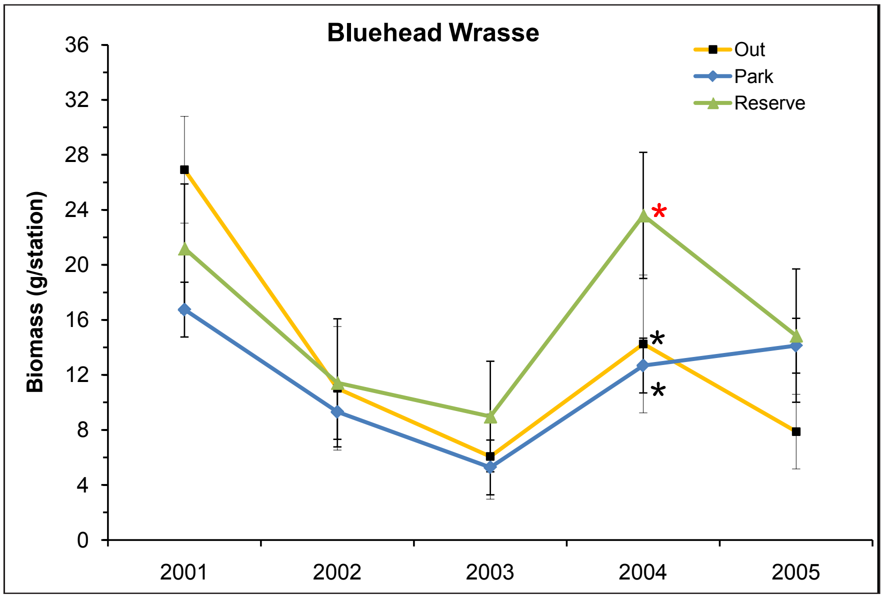


*Figure 5.11. Mean ± S.E. values of Bluehead Wrasse biomass by management strata over the five year sampling period spanning 2001-2005. * indicates significant differences among strata within a given year (p<0.004, Bonferonni corrected Kruskal-Wallis tests).; p>0.004 for differences among years within management strata; N=150).*

Mean biomass of Yellowtail Snapper did not vary significantly by management strata, but varied through time. Mean Yellowtail Snapper biomass remained stable between 2001 and 2003 for all three strata, then increased drastically at Park and Reserve sites in 2004, with a further increase at reserve sites in 2005 (Figure 5.12). Mean biomass of Striped Parrotfish also varied significantly among years but not among management strata (Figure 5.13). Striped Parrotfish biomass was more variable through time at sites in the outside and Park strata compared with sites in the reserve. In 2003, mean Striped Parrotfish biomass plummeted from 124 g/station in 2002 to only 4 g/station in the outside stratum, and only rebounded to 39 g/station by 2005 (Figure 5.13). Similarly, mean biomass of Striped Parrotfish at park sites plummeted from 40 g/station in 2002 to 1.5 g/station, but rebounded to as much as 79 g/station in 2005. In contrast, mean Striped Parrotfish biomass at Reserve sites remained near 50 g/station until 2003 then decreased to 20 g/station in 2005.

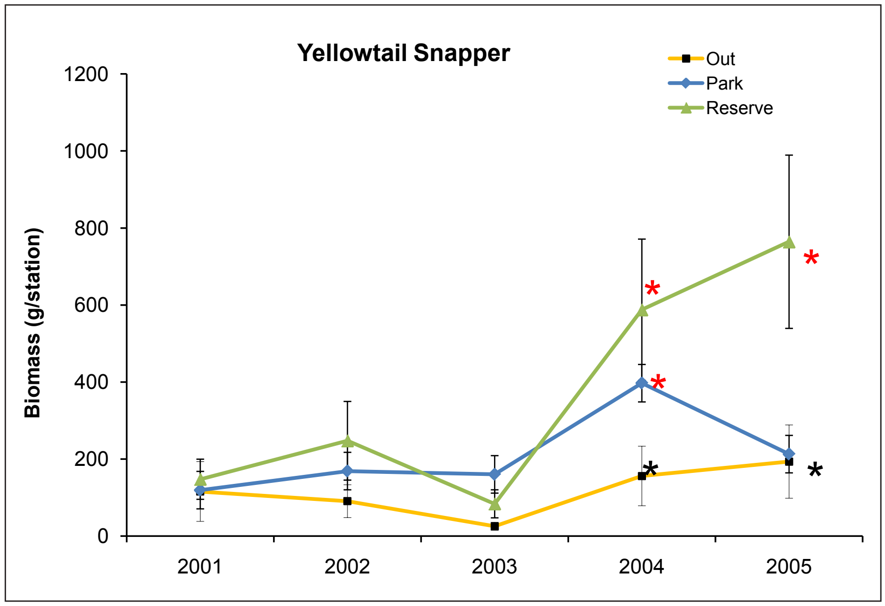


*Figure 5.12. Mean ± S.E. values of Yellowtail Snapper biomass by management strata over the five year sampling period spanning 2001-2005. * indicates significant differences among strata within a given year (p<0.004, Bonferonni corrected Kruskal-Wallis tests).; p>0.004 for differences among years within management strata; N=150).*

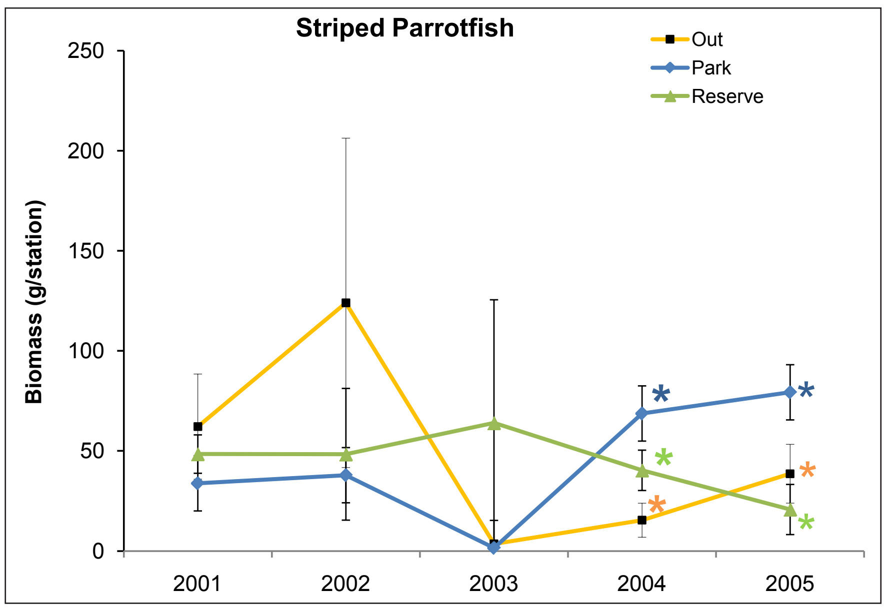


*Figure 5.13. Mean ± S.E. values of Striped Parrotfish (*Scarus iserti*) biomass by management strata over the five year sampling period spanning 2001-2005. * indicates significant differences among strata within a given year (p<0.004, Bonferonni corrected Kruskal-Wallis tests).; p>0.004 for differences among years within management strata; N=150).*

Maps of the spatial distribution of total abundance and total biomass for the twelve focal species are shown in Figures 5.14 and 5.15. Interestingly, only three of 30 stations appeared dominated by a single species' abundance. Bluestriped Grunt (*Haemulon sciurus*) was the most abundant of the 12 species at two sites: station 1864, which was located at the northeast just outside the boundary of the park and station 7265, located just outside the southwest boundary of the park (Figure 5.14). Yellowtail Snapper was the most abundant of the twelve focal species at station 9807, which was one of two most western location sampled within the TER (Figure 5.14). At the other 27 stations, total abundance was fairly well partitioned among the twelve focal species. In a similar fashion, only two of 30 stations were dominated by the biomass of a single species. Station 6493, located just inside the southern boundary of the park, had mainly Bluestriped Grunt biomass. Station 12379, located south of the TER and west of the park, had relatively high Striped Parrotfish biomass (Figure 5.15). Again, total biomass was fairly well partitioned among the twelve focal species at the remaining 28 stations (Figure 5.15).

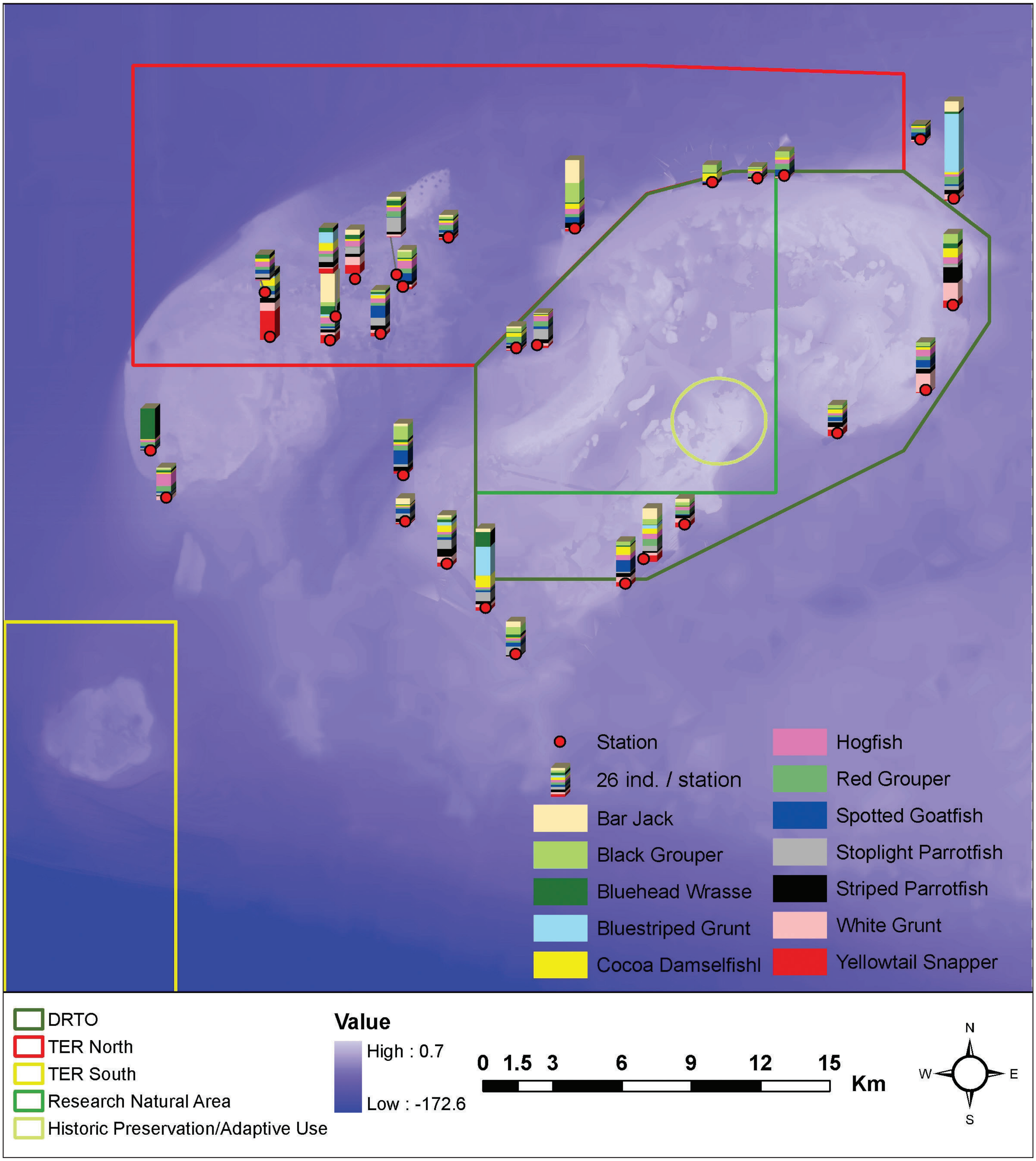


Figure 5.14. Distribution and abundance (number of individuals) of 12 selected species at 30 stations in the Tortugas region.

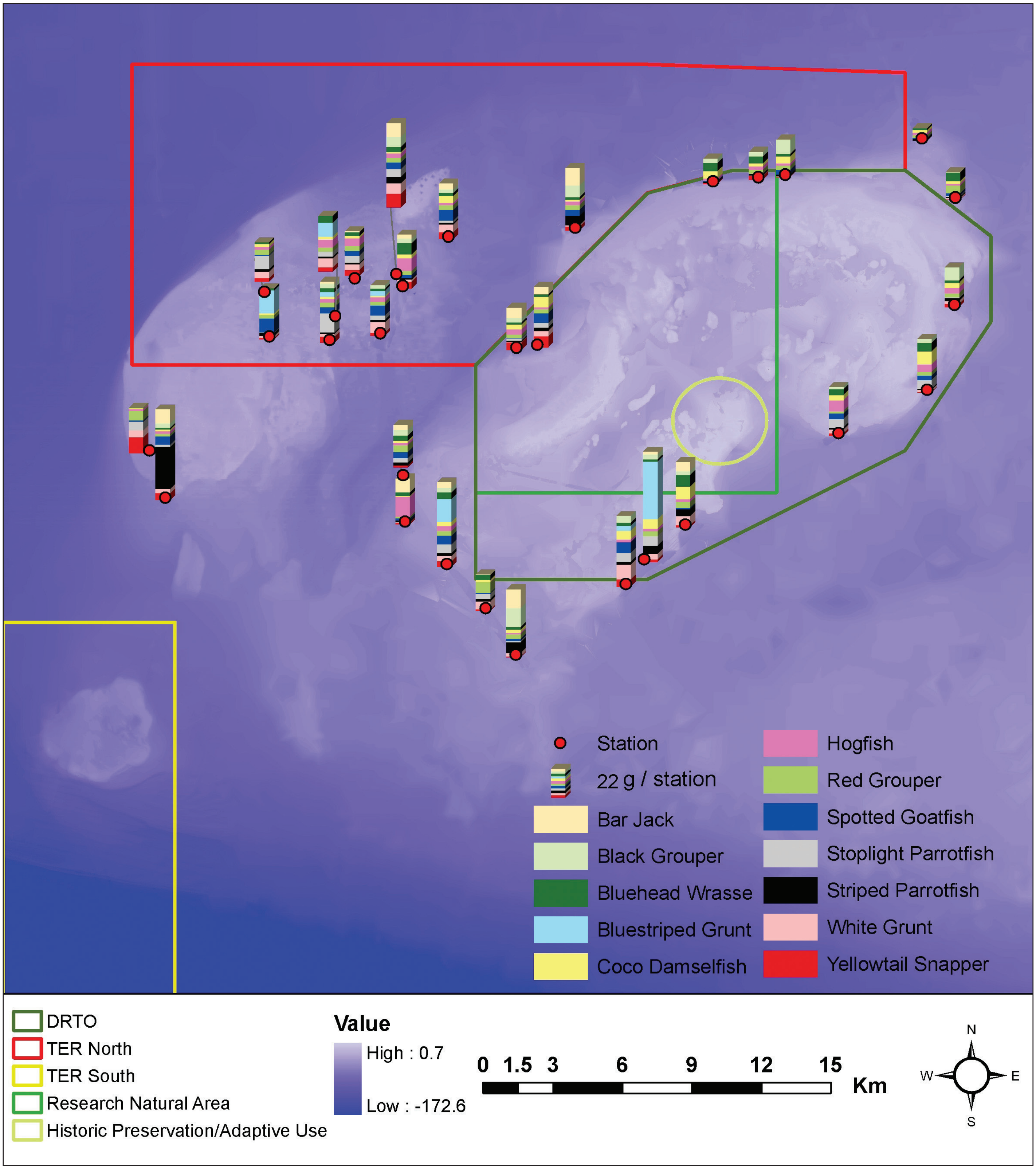


Figure 5.15. Distribution and biomass (g/station) of 12 selected species at 30 stations in the Tortugas region.

SECTION B. ADDITIONAL CENTER FOR COASTAL FISHERIES AND HABITAT RESEARCH STUDIES

Fish-Habitat Relationships

These analyses focused only on those samples from 2001-2003 which had complete environmental data available, with the sand transect and reef transect of each station considered a distinct sample (n=174). Environmental variables included the following:

- Scleractinian coral cover
- Sand cover
- Rubble cover
- Macroalgae cover
- Microalgae (turf) cover
- Seagrass cover
- Octocoral cover
- Fire coral cover
- Sponge cover
- Non-coral cnidaria cover
- Rugosity
- Fire coral cover Cover of other invertebrates (those not included in above-described groups, including anemones and sea urchins)
- Time of Day (morning, afternoon, or evening)
- Slope (measure of elevation along transect)

For benthic flora and fauna, the taxonomic resolution used here is fairly coarse, and habitat associations might have been stronger if species, genus or even family designations were used. However, being able to confidently identify an organism to these fine-scale taxonomic levels from the video and photographic survey methods used proved difficult and unreliable. Thus, the taxonomic levels used here are broad, but represent the highest level of confidence in consistent organism identification.

For univariate analyses, stepwise backward regressions were completed for abundance patterns of each of the 12 focal species, as well as the community metrics of diversity, species richness and total abundance. For multivariate analyses, canonical correspondence analysis compared the sample-by-environment matrix with the sample-by-species matrix to determine species-environment associations. Although 184 species were observed throughout the sampling, this number had to be reduced to a more manageable number so that results could be interpretable (see Appendix II, Table B). Thus, those non-focal species which had a total abundance and/or total sighting frequency of less than five were removed from the dataset, resulting in a final list of 64 species included in the multivariate analysis.

As shown in Table 5.6, the regression analyses demonstrated that each species responded to a unique set of habitat characteristics, with some environmental variables showing opposite relationships for different species. R^2 values were somewhat low, but being able to account for even a seemingly low proportion of variation, especially when using a limited set of environmental variables, should be considered useful in improving the ability to predict and model fish distributions. Furthermore, these analyses focused only on coarse environmental variables, and did not consider the multitude of other factors that can affect distribution patterns of fish, such as, but not limited to, inter- and intra-specific competition, predator-prey interactions, larval recruitment, spawning behavior, oceanographic processes operating at multiple spatial scales, temperature, natural disturbances (storms) and disease.

Scleractinia cover, fire coral (*Millepora*) cover, slope, and rugosity were the most frequent significant predictors of fish species patterns. Not surprisingly, covers of sand, macroalgae, microalgae and seagrass were very poor predictors of the observed distributions of all focal species, which are generally reef-associated species. The low predictive power of algae and seagrass cover suggests that, (1) fishes are not responding to benthic vegetation patterns, and/or (2) the level of resolution used in this study was too coarse to detect any fish-vegetation relationships (i.e., perhaps if algae and seagrass had been identified to genus or functional form, then better relationships would have emerged). When significant, high rugosity was positively associated with fish species, highlighting the importance of complex benthic topography as preferred habitat.

Only two species (Cocoa Damselfish and White Grunt, *Haemulon plumierii*) showed any relationship to time of day, suggesting that even though the sampling protocol did not control for time of day, this factor likely did not greatly influence the data. Additionally, depth was only significantly related to one species (Striped Parrotfish),

so the variability in depth across stations and management strata can be assumed to have little effect on fish distributions as well.

Of the 15 environmental variables considered, only six were significant predictors for at least one of the community metrics evaluated (Table 5.7). Species richness and species diversity were similar, but not identical, in the habitat variables to which they were significantly related. High rugosity was associated with more species and more individuals, again implicating the importance of benthic topographic complexity for many individuals and species. Macroalgae cover, which was not a significant predictor for any of the 12 focal species, was a significant predictor of community-wide fish metrics. Rubble and octocoral also proved to be important predictors of fish communities. Surprisingly, coral cover, which was associated with patterns of several specific species, was not significantly associated with any of the three community metrics analyzed.

Table 5.6. Results of stepwise backward multiple regression analyses testing for habitat associations with each of the 12 focal species. A (+) indicates a significant positive relationship, (-) indicates a significant negative relationship, and an empty cell indicates no significant relationship. Note that the habitat factor "rugosity'" represents true rugosity, and not the inversely-related rugosity index value.

Species	Scleractinia	Sand	Rubble	Macroalgae	Microalgae	Seagrass	Octocoral	Firecoral	Sponge	Non-coral Cnidaria	Other invertebrates	Time	Depth	Rugosity	Slope	R^2
Bar Jack															+	0.055
Black Grouper			+													0.101
Bluehead Wrasse				+												0.028
Bluestriped Grunt							+	+			+					0.215
Cocoa Damsel								+				+		+		0.139
Hogfish	-								+						+	0.149
Red Grouper	-	-							+							0.256
Spotted Goatfish							+								+	0.069
Stoplight Parrotfish	+													+	-	0.206
Striped Parrotfish										+			-	+		0.261
White Grunt	+		-					+				-			+	0.353
Yellowtail Snapper								+							+	0.402

Table 5.7. Results of stepwise backward multiple regression analyses testing for habitat associations with each of the community metrics. A (+) indicates a significant positive relationship, (-) indicates a significant negative relationship, and an empty cell indicates no significant relationship. Note that the habitat factor "rugosity'"represents true rugosity, and not the inverse rugosity index value.

Species	Scleractinia	Sand	Rubble	Macroalgae	Microalgae	Seagrass	Octocoral	Firecoral	Sponge	Non-coral Cnidaria	Other invertebrates	Time	Depth	Rugosity	Slope	R^2
Diversity			+	+							+				-	0.319
Species Richness			+	+			+							+		0.705
Abundance				+			+							+	-	0.250

Results of the Canonical Correspondence Analyses (CCA) show strong fish-habitat associations (Figures 5.16-5.18). Eigenvalues for Axes 1 though 3 (Axis 3 is not represented in the following figures) are 0.361, 0.123, and 0.087 respectively. Axis 3 has a particularly low eigenvalue and thus is not considered relevant for future discussion. Axis 1 represents a gradient of benthic complexity. The negative end represents high cover of sponge, scleractinia, sponge, rock and octocorals, as well as large slopes and high rugosity. The positive end of Axis I represents low rugosity, high sand, and increased microalgae cover. The positive end of Axis 2 represents high microalgae cover, while the negative end of this axis represents high scleractina cover, rock cover, slope and depth. Reef transect samples generally lie towards the left side of the plot, while sand transect samples generally tend towards the right side of the plot. The location of sample points is based on their relative abundances of fishes; samples are located closest to the points of the species found at those samples. Samples with more similar fish community profiles appear closer together, thus, sand stations appear to have more variable fish community profiles than do the reef samples, which, based on the tight clustering, have consistent patterns in relative species abundances. Although not absolute, the fish species do tend to segregate into reef-associated and sand-associated clusters.

The length of the environmental vectors provides an indication of the relative importance of each environmental variable in influencing fish patterns. Thus, the most important variables, in descending order of vector length, are: rugosity, sand cover, sponge cover, slope, octocoral cover, scleractinia cover and rock cover. These variables likely hold the highest predictive power for predicting fish community patterns from environmental characterizations and identifying ‘hotspots’ for fish communities. The variables with the shortest vector lengths, and thus the least influence on fish patterns were time of day, cover of other invertebrates, macroalgae cover and depth.

The projection of species points along environmental vectors suggests that increased abundances of Gray Snapper (*Lutjanus griseus*), Banded Butterflyfish (*Chaetodon striatus*), Ocean Surgeonfish (*Acanthurus bahianus*), French Grunt (*Haemulon flavolineatum*), Schoolmaster (*Lutjanus apodus*) and Bluestriped Grunt were each associated with high cover of scleractinian corals, high rock cover and high slopes. Habitats with high rugosity and increased covers of octocoral and sponges were associated with highest abundances of Gray Snapper, Banded Butterflyfish, French Grunt, Schoolmaster, Bluestriped Grunt, Longspine Squirrelfish (*Holacanthus rufus*), Porkfish (*Anisotremus virginicus*), Scamp, Squirrelfish (*Holacanthus adscensionis*), Creole Wrasse (*Clepticus parrae*) and Foureye Butterflyfish (*Chaetodon capistratus*). Less complex habitats characterized by high bare sand and microalgal cover were associated with high abundances of several goby species, Yellowhead Jawfish (*Opistognathus aurifrons*), Sand Perch (*Diplectrum formosum*), small parrotfish species, small bass species and Slippery Dick (*Halichoeres bivittatus*).

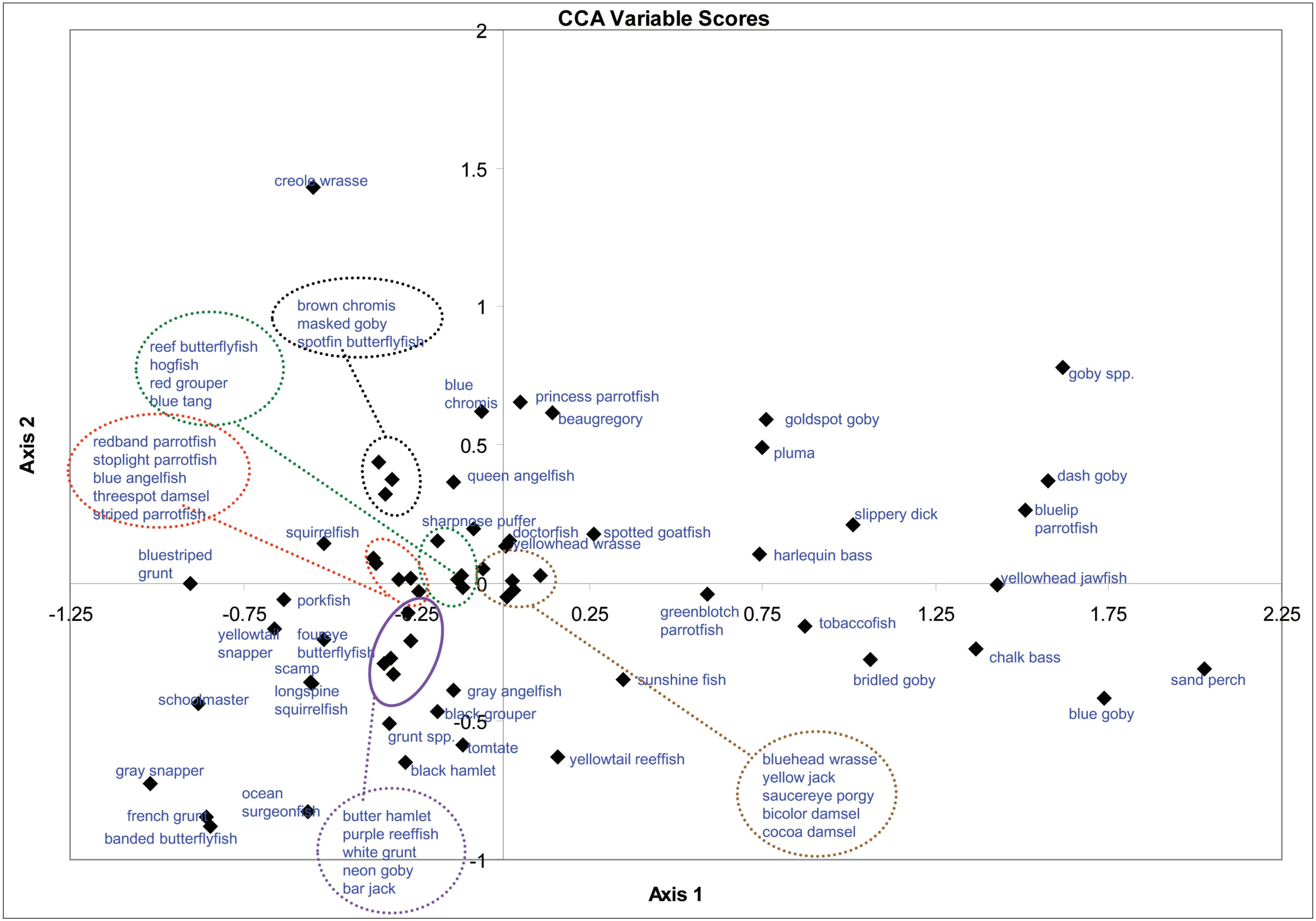
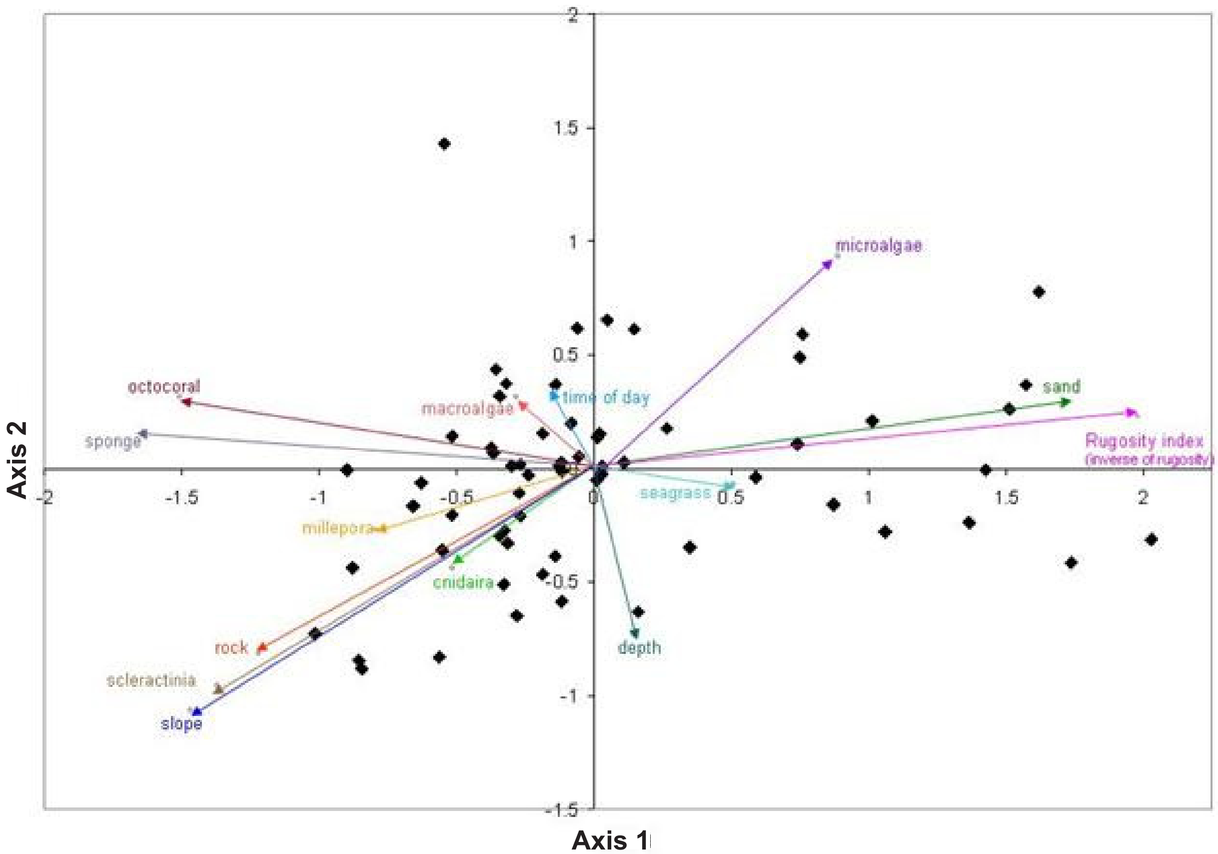


Figure 5.16. Species Canonical Correspondence Analyses (CCA) scores, with the noticeable segregation of reef-associated species (tending towards the left) from sand-associated species (tending towards the right). Proximity of species points indicates the degree of similarity with respect to distribution patterns and habitat preferences. **NOTE**: *Axis 3 is not represented.*



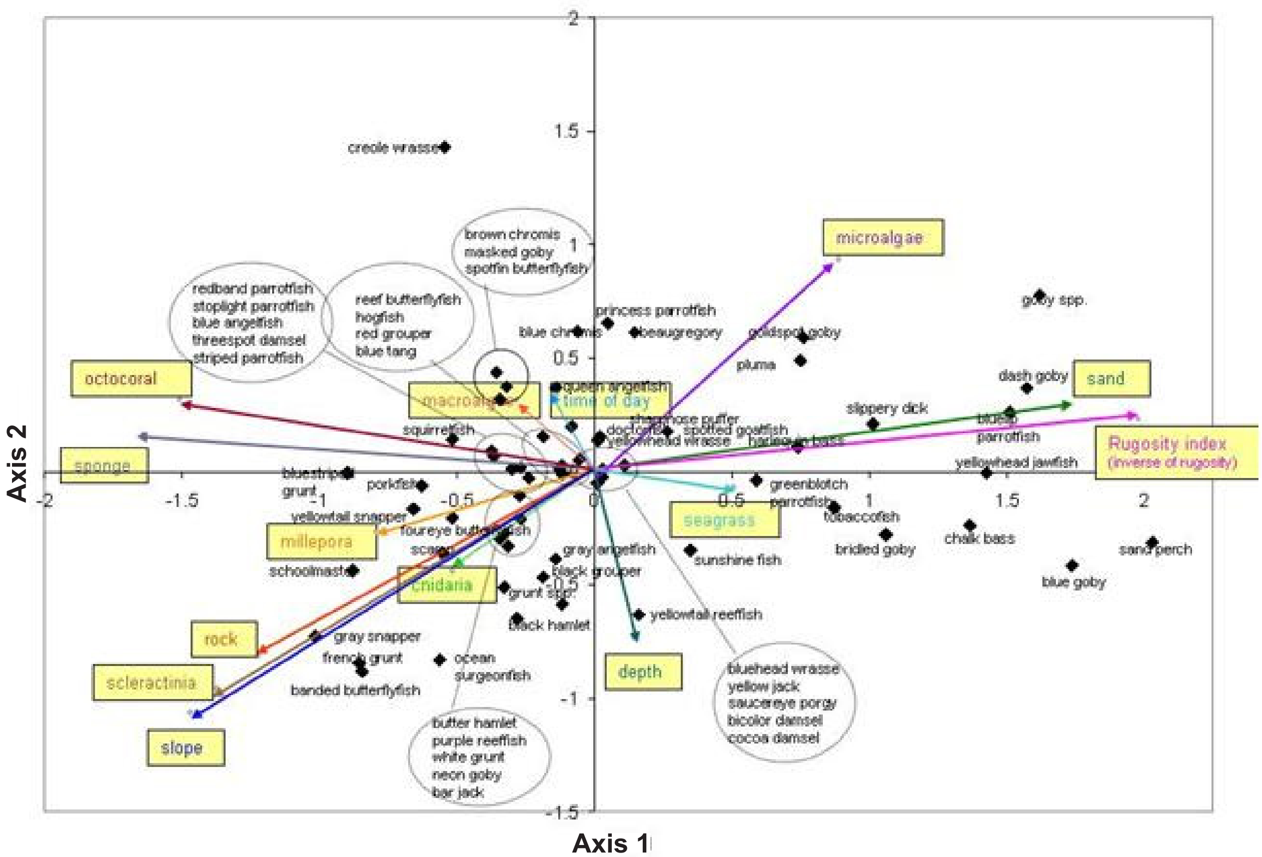


Figure 5.17. Plot of species CCA scores with environmental vectors. The top graph does not include labels for species points (for readability purposes), while lower graph does include species labels. Vector length is proportional to relative influence of that variable compared to other environmental variables. NOTE: the vector labeled "Rugosity Index" actually represents the inverse of rugosity. Thus, habitats that are more rugose (meaning the chain covered less distance), actually have a lower rugosity index value. NOTE: Axis scales differ from previous CCA figures, axis 3 is not represented .

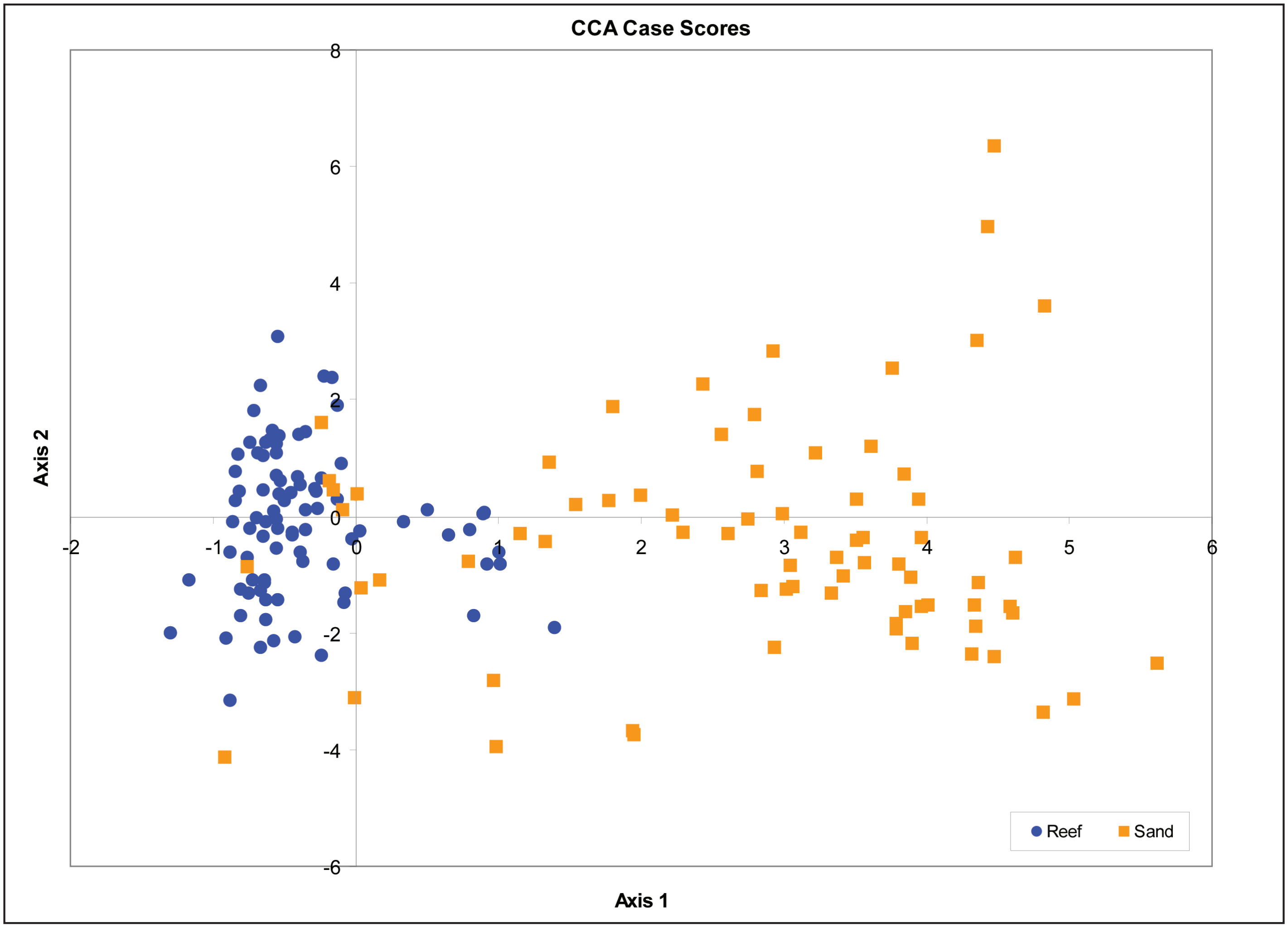


Figure 5.18. Sample CCA scores, with the reef samples (tending towards left) segregating from the sand samples (tending towards right). Each sample represents a unique combination of station and sampling year. Proximity of points represents the degree of similarity with respect to relative abundances of fish. ***NOTE:*** *Axis scales differ from first CCA figure; axix 3 is not represented.*

Mapping Nighttime Fish Distributions Using Scientific Echosounders

The objective of this work was to elucidate nighttime fish distributions and feeding patterns. Most other efforts characterizing fish distributions, including those studies by CCFHR and University of Miami-Rosenstiel School of Marine and Atmospheric Science (UMRSMAS), are, due to the nature of the survey methods, limited to daytime surveys. However, knowledge of nighttime fish activity and movements can also provide insight when making decisions regarding marine protected area (MPA) design, since it is known that fishes often leave reef habitats to feed. The surveys are continuous along parallel transects and provide data at high resolution and over a range of spatial scales (sub-meter to kilometer). This particular study will be useful in determining if the TER boundaries encompass areas being utilized by reef fishes during night time hours. This information can be applied to MPA design, to ensure that boundaries include not only specific habitat features (i.e., reefs and hard-bottom), but also the particular areas that are known to support the coral reef fish communities. A limitation of this approach is that the densities reported will be a composite of all fishes present, as acoustics cannot discriminate species. On the other hand, acoustics can provide reasonable estimates of individual fish sizes, which can be compared to size classes and counts observed during diver fish community surveys.

The acoustic data were collected using a Simrad EK60 splitbeam echosounder and transducer operating at 120kHz during multibeam hydrographic surveys. The first surveys were conducted in small polygons around the fixed monitoring stations established by CCFHR during 2004. Additional data were collected during multibeam hydrographic mapping surveys in 2008 and 2009. Data have been processed and georeferenced and geodatabases are being created with individual fish size (estimated from acoustic target strength), time of observation, depth and latitude/longitude position. Analysis is underway to assess the distribution of fish densi-

ties in relation to bathymetric metrics (e.g., bottom roughness, slope, complexity) and habitat types as well as changes in distribution in relation to time as an indicator of fish behaviors and migrations on-off reef habitats. Additional comparisons are being made between the diver visual observations and acoustic densities to aide in the interpretation of each survey method.

Characterization of Reef Fish Spawning Aggregations in the TER

The work of Burton et al. (2005) describes one possible effect of the TER, particularly the TER South, on fish patterns. Known Mutton Snapper spawning aggregations exist within the now-protected Riley's Hump area of TER South. Aggregations were observed annually from 1999 to 2004 to document abundances and behavior of aggregating Mutton Snappers. In a published research note, Burton et al. (2005) report that spawning aggregations appear to be increasing in the Riley's Hump area and more Mutton Snapper are aggregating and appear to be less wary of divers, a condition commonly observed in spawning individuals that might otherwise be solitary and wary of diver presence. It is hypothesized that the increased number of Mutton Snapper aggregating at Riley's Hump may be at least partially due to the increased protection afforded to the Mutton Snapper following the establishment of the TER South in 2001.

Data Collection and Analysis Methods

Several visual surveys along 30 m transects were completed annually at each of 15 stations. Ten stations were sampled from 1999 through 2004, while five additional sites were added in 2002 and surveyed through 2004. Mutton Snapper abundance, behavior and lunar phase were recorded for each transect. Detailed methods can be found in Burton et al. (2005).

Results and Discussion

In 1999, sighting of solitary Mutton Snapper were reported for 27% of the surveys. In 2000, frequency of Mutton Snapper observations increased to 83%, although all sightings were still of solitary individuals. Individuals observed in both 1999 and 2000 demonstrated diver-avoidance behavior. In 2001, a tightly packed group of 10 individuals was observed at one survey station. In 2002, a group of Mutton Snapper swimming in a tightly packed group was again observed at the same station as 2001, although the number of Mutton Snapper increased dramatically to 75-100 individuals. In 2003, a group of 75-100 Mutton Snapper were again observed at the same station, although this time they were widely dispersed and showed more extreme diver-avoidance behavior. Also in 2003, but at a different station, a widespread aggregation of 200 individuals was observed; by 2004, 300 individuals were observed at this same station. These large aggregations observed in 2003 and 2004 were composed of actively swimming Mutton Snapper that showed no concern of diver presence. As surveys were completed during the day, and spawning activity is thought to occur at dusk, actual spawning was not witnessed, but the large groups of fish observed in 2003 and 2004 are assumed to be spawning aggregations based on the fish behavior and on the timing (one or two days after the full moon) and location of the aggregations.

Softbottom Shelf Surveys

The reserve is anticipated to act as a refuge for pink shrimp (*Penaus duorarum*; Figure 5.19) targeted by a trawl fishery of the soft bottom shelf north of the Tortugas Bank. Approximately 70% of the TER North consists of unconsolidated shelf habitat and trawling for pink shrimp likely affected its habitat structure, sediment characteristics (Turner et al., 1999) and invertebrate infaunal and epifaunal biomass (Jennings et al., 2001) and size structure (Duplisea et al., 2002). In addition to pink shrimp, the softbottom shelf is home to a cryptic fish community dominated in terms of bio-

*Figure 5.19. Photos of large pink shrimp (*Penaus duorarum*; left) and various species of flatfish (right).*

mass by flatfish (Figure 5.19) and diverse assemblages of crustaceans, echinoderms, annelids and molluscs. Video observations in the shallower portions (<90 feet) of this soft-bottom environment within the TER North unexpectedly documented hard bottom outcrops and less surprisingly, extensive macroalgae and the occasional meadow of the seagrass *Halophila decipiens*. The presence in experimental samples of juvenile reef fishes including snappers and groupers suggests these areas act as juvenile habitat for species that will migrate with growth to the reef habitats of the banks. The shelf surrounding the banks is expected to represent an important feeding ground for adult reef fishes that occupy the banks as soft bottom invertebrates are a primary source of food for a variety of reef fish families (Randall, 1967). A wide variety of generalized reef fish predators shelter on the reef during the day and disperse at dusk to feed in surrounding habitat (Hobson, 1974). Important reef fish families that exhibit such behavior include; Holocentridae, Priacanthidae, Apogonidae, Mullidae, Scianidae, the commercially important families Lutjanidae and Haemulidae as well as some species of Serranidae (Randall, 1967). Energy flow to the reef from surrounding soft bottom communities via these nocturnally migrating reef fish predators has been hypothesized to be of fundamental importance to coral reef system energy budgets (Ogden and Ehrlich, 1977) and to account for the higher than expected productivity of reef fish fisheries (Huntsman, 1979).

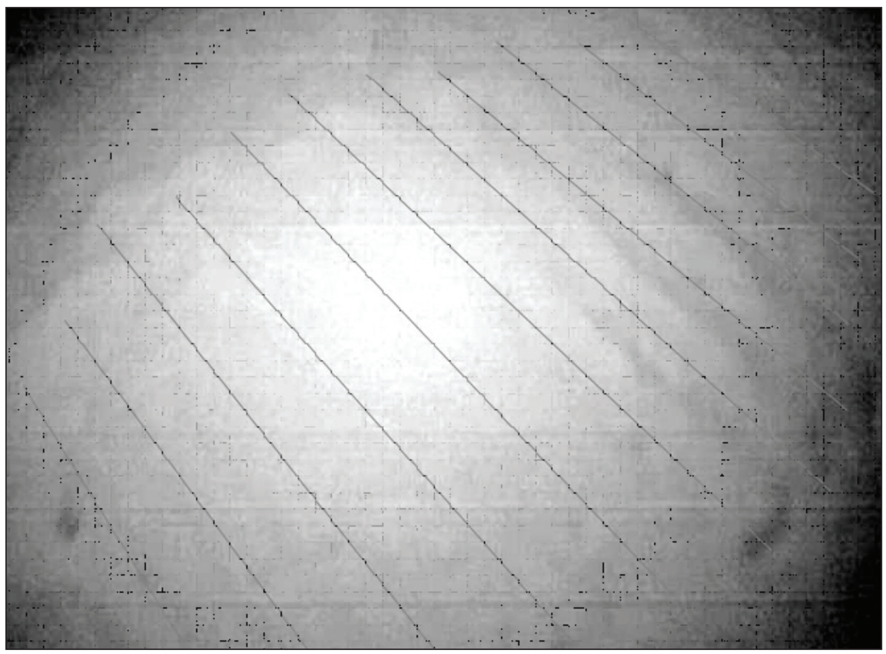


Figure 5.20. Trawl tracks in TER boundary revealed by video cameras. Lines added for emphasis of the trawling grooves left in the seafloor.

To evaluate the impact of the TER North on the soft bottom communities within its boundaries we collected experimental trawl samples from, and video observations of, the softbottom shelf around the northern and eastern boundary of the reserve. Paired, experimental beam trawl samples (2 m bar width) and video drift camera surveys were conducted both within and outside the boundary of the TER North to determine if any differences in pink shrimp abundance (or other potential shrimping by-catch species) could be detected. During our sampling commercial shrimp trawling vessels of approximately 80 feet were fishing outside of the boundary during all cruises. Video cameras drifted across the seafloor just a few hundred meters north of the TER boundary revealed extensive trawl tracks in the soft bottom (Figure 5.20). Experimental trawling was conducted after full dark during our regular cruises in 2002, 2003 and 2005 at randomly selected distances along the northern boundary. Sampling in the observed active fishing area ("Open") was within 500-1,000 m of the northern boundary. Sampling within the TER was typically 1,000-2,000 m within the boundary. During 2005 we conducted an additional series of trawls as close to the boundary as navigationally possible to determine if the distribution of pink shrimp was indicative of a gradient of fishing pressure.

Computations of the average number of *P. duorarum* per trawl from the samples taken within the TER North were made and compared with those take just outside in the active trawling grounds (Figure 5.21). In all years there was evidence of greater shrimp abundance within the TER North. A gradient of shrimp density was evident in 2005 samples that would be expected to result from variation in fishing pressure or spillover of shrimp from the TER North. Because sampling of the shelf started after the reserve was established we do not know if this gradient existed prior to the creation of the TER. Comparative sampling of the softbottom shelf within and outside the TER North support the hypothesis that soft bottom communities can respond quickly to relaxation of the trawling pressure and that establishment of the reserve has positively affected pink shrimp abundance within its confines. As time passes without the disturbance caused by trawling,the stability and size of the shelf's sessile invertebrate fauna and the motile animals that associate with it should increase. Such changes

would be expected to increase energy flow to the banks by improving feeding conditions for reef fishes and improving the shelf's capacity to serve as nursery habitat for juvenile reef fishes.

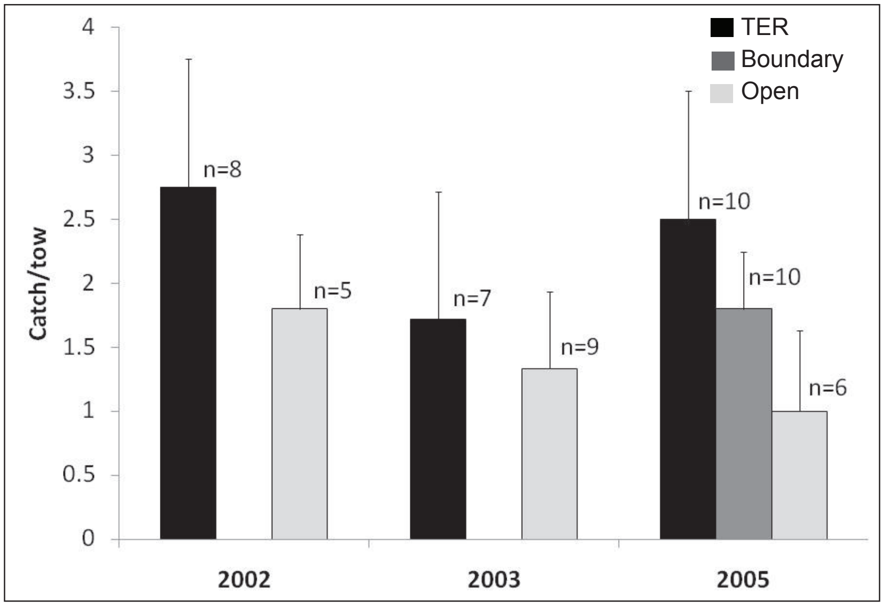


Figure 5.21. Comparison of the average number of pink shrimp captured per tow from trawl samples taken within the TER, in the active pink shrimp fishing ground (OPEN) and at the boundary in 2005.

Characterization of Reef Fish Trophic Structure Via Stable Isotope Research

Stable isotope analysis was used to estimate the contribution of benthic primary production to fish and shellfish in the TER. Samples of fish, phytoplankton, benthic microalgae, benthic macroalgae, seagrass and crustaceans (crabs and shrimp) were collected and analyzed for stable Carbon (C) and Nitrogen (N) isotope composition. Food web analysis utilizes the distinct isotope characteristics of primary producers, and the fact that consumers accurately reflect the isotopic signature of their diet, to estimate the contribution of food sources in an animal's diet (DeNiro and Epstein, 1981; Takai et al., 2002). Phytoplankton, which are the only source of primary production in the water column, have $\delta^{13}C$ values between -17 and -21‰, and can thus be distinguished from all benthic primary producers, which have average $\delta^{13}C$ values ranging between -7.5‰ (seagrass) to -15.2‰ (benthic algae). N isotope values of primary producers show less variability, with mean values between 2 (coral) and 5.7‰ (phytoplankton; Figure 5.22).

Over 200 fish and invertebrates were collected from the TER, and included groupers, snappers, flounders and shrimp. Dual isotope plots reveal relationships between consumers and the available primary producers (Figure 5.22). In the TER, nearly every fishery organism had a $\delta^{13}C$ value that was enriched compared to phytoplankton, and the average value of all fish was -15.4‰. Fish relying exclusively on phytoplankton production would be expected to have $\delta^{13}C$ values between -16.8 and -17.8‰, depending on their trophic level and fractionation factors. A simple mixing model comparing pelagic production and a pooled value for benthic primary production suggests that well over half of the fishery production in the TER is provided by corals, benthic algae and/or seagrass. For some organisms, the reliance on benthic production is much higher. Lane Snapper (*Lutjanus synagris*), Hogfish, White Grunt and Scorpionfish (Scorpaenidae) are among the fish species with average $\delta^{13}C$ values greater than -15 ‰, indicating substantial reliance on benthic primary production (Figure 5.22). In contrast to results from the West Florida Shelf, stable isotope analysis did not indicate a strong trophic contribution of seagrass primary production to shrimp diets (Burke et al., 2004; Fonseca et al., 2006). N isotope values indicate one to three trophic levels separate herbivores (shrimp and parrotfish) from top predators including snapper and grouper (Figure 5.22).

An important role for benthic algae to fishery production in shallow marine waters has been supported both by modeling and stable isotope analysis of food webs (Okey et al., 2004; Takai et al., 2002). Clearly, benthic algae are an important part of the fisheries food web in the Dry Tortugas, as are corals. Overlapping endmember $\delta^{13}C$ values of corals and algae make it difficult to distinguish between benthic primary producer groups with stable isotope analysis.

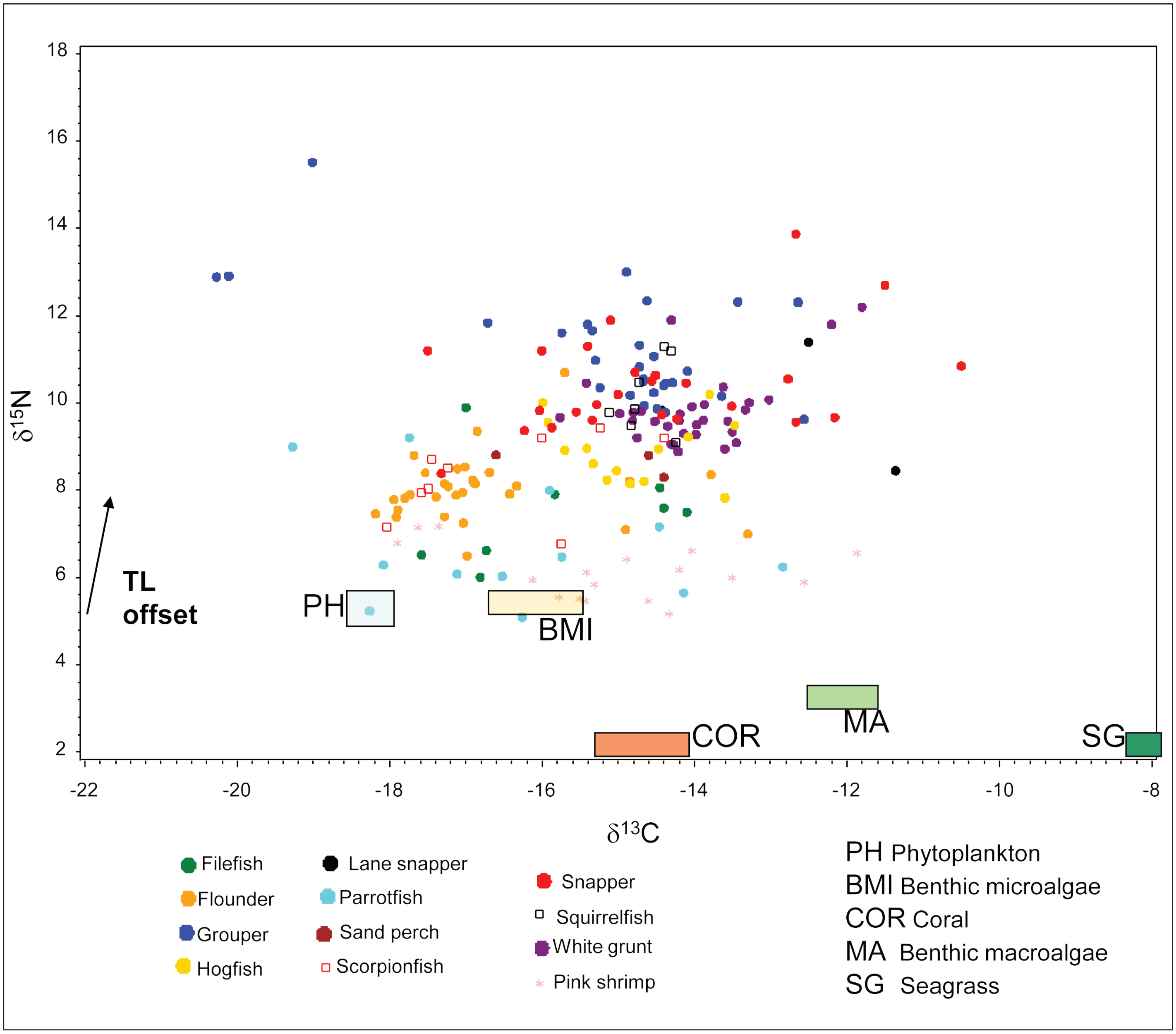


Figure 22. The $\delta^{13}C$ and $\delta^{15}N$ values of consumer organisms and primary producers collected in the TER between 2000 and 2004. Rectangles represent the mean and standard error of values for primary producers, including phytoplankton (PH), benthic microalgae (BMI), corals (COR), benthic macroalgae (MA) and seagrasses (SG).

SUMMARY AND CONCLUSION

In summary, the suite of studies conducted by CCFHR in the Tortugas region has yielded several interesting results concerning the effects of TER implementation on reef fish assemblages. They include:

- Variation in species richness and total fish abundance over time were similar across for the reserve, park, and areas outside.
- There were no significant differences among management strata in the ranks of the most abundant species, which suggests that fish assemblage composition inside the ecological reserve and park were not significantly different from that found outside. This finding was also corroborated by ANOSIM analyses which showed that occurrence of species were very similar across management strata (i.e., reserve, park, and areas outside).
- With the exception of Yellowtail Snapper, occurrence and abundance of exploited species was low across all management strata..
- Yellowtail Snapper showed increasing trends in abundance, biomass and size within the reserve. In contrast, none of the non-exploited species for which data were analyzed showed increasing trends. The disproportionate increase within the reserve of this key commercial species suggest that the implementation of the reserve effectively protected exploited fishes within its confines during the survey period.
- Mutton Snapper may have reformed aggregations in the Tortugas region. The study by Burton et al. (2005) provides preliminary evidence that spawning aggregations were beginning to re-form on Riley's Hump. Although the numbers of Mutton Snapper observed do not rival those of anecdotal descriptions of Mutton Snapper abundances during previous peaks of exploitation, the documented increase in both occurrences of aggregations and numbers of aggregating Mutton Snapper provide encouraging evidence that the Mutton Snapper stock may be recovering and increasing spawning activity. The authors note that their preliminary data suggest that the implementation of the TER South has increased numbers of Mutton Snapper in area. The TER South may both be protecting both the individuals during non-spawning times, and the aggregations during spawning times.
- CCA analyses indicated that topographic complexity (e.g., rugosity) was most predictive of species sighting frequency, abundance and richness.

CCFHR's approach to examine TER implementation effects contrasted sharply with that used by UMRSMAS/NMFS, which monitored and assessed reef fish assemblages at multiple hardbottom habitats over a much larger spatial domain (c.f. Chapter 3). Inherent differences in sampling approaches (e.g., 60 x 4 m versus 200 x 200 m sample plots, permanent versus random stations, or single versus multiple hardbottom habitats); sensitivity of reef fish population metrics to different sampling approaches, and high spatial and temporal variability of fish assemblages; suggest comparisons of the results of these two studies should be made with caution. Nevertheless, several of the observed patterns in reef fish assemblages were similar among the two studies, which suggest that effects of TER implementation described for 2001 to 2005 were real rather than superfluous. Following are summary statements comparing findings among both studies.

Temporal Trends In Assemblage Composition

Similar to CCFHR, UMRSMAS/NFMS observed that Tortugas reef fish communities were relatively stable over time, both in terms of fish community structure and fish species sighting frequencies. The UMRSMAS/NMFS study reported that 45 of the 50 most frequently observed species in the baseline years were also among the 50 most frequently observed species in 2006. Likewise, CCFHR study reported that 15 species were consistently included on the annual lists of the 25 most frequently observed species. In addition, UMRSMAS/NNMFS data also indicated that exploited species were more frequently observed during the latter years of surveys, a finding that was consistent with CCFHR observations.

For the 12 focal species, UMRSMAS/NMFS reported domain-wide decreases in abundances for exploited Hogfish and Red Grouper over time; CCFHR found that abundances of these species was stable during the

period or in the case of the Hogfish within the reserve appeared to increase at sand-reef interfaces over time. CCFHR also observed significant increases between baseline (2001) and later year (2004, 2005) abundances for exploited White Grunt and Yellowtail Snapper, whereas UMRSMAS/NMFS reported no change over time in domain-wide abundances for these two species. Both studies did, however, find that Black Grouper abundances remained relatively stable over time. CCFHR study observed no changes in abundances of the non-exploited focal species; however, UMRSMAS/NMFS found that 2006 abundances for seven non-exploited species were significantly different (increased or decreased) from baseline (2001) estimates.

Interestingly, temporal trends in sighting frequencies of some focal species differed between the two studies. UMRSMAS/NMFS observed increased domain-wide percent occurrence between baseline surveys (1999-2000) and 2006 surveys for Mutton Snapper, but declines in abundance for Red Grouper, Gray Snapper and Hogfish. In contrast, the CCFHR study revealed increased percent occurrence for Mutton Snapper, Gray Snapper, and Hogfish between baseline (2001) and 2005 surveys, but relatively stable percent occurrence for Red Grouper at sand-reef interfaces.

Temporal trends of focal species within each management strata were not always concordant between the CCFHR and UMRSMAS/NFMS studies. For example, UMRSMAS/NMFS identified far more significant differences in species' abundances between baseline and later surveys than did the CCFHR study. Interestingly, UMRSMAS/NMFS reported a decline in long-term (1999 to 2006) abundances of Hogfish in fished areas, while CCFHR found evidence of an increase in long-term (2001-2005) Hogfish abundances in the TER. Furthermore, while the UMRSMAS/NMFS study reported significant increases or decreases in abundance for both exploited and unexploited species; the CCFHR study found only significant increases in abundances for two exploited species, particularly in the TER. The previously mentioned differences in study design may account for some of the disparities in these results; however, since both methods rely on snapshot surveys of fish assemblages, one must consider the inherent variability of fish community patterns.

Changes in Size Structure and Biomass

CCFHR found that average size and total biomass of Yellowtail Snapper showed increasing trends within the reserve. The absence of this trend in the UMRSMAS/NMFS study is probably due to its focus on hard-bottom habitat on the banks rather than their margins which appear to represent preferred habitat for a variety of reef fishes such as Yellowtail Snapper and White Grunt that depend on the surrounding soft bottom shelf as a feeding ground. The UMRSMAS/NMFS study found that the proportion of exploited-phase individuals of both Black Grouper and Red Grouper were directly related to the extent of resource protection, with the no-take reserve having highest proportions of exploited phase of each species. CCFHR did not find any differences in size structure of Red or Black Grouper among the different management zones, probably because that study was focused at sand-reef interfaces which represented a much smaller spatial scale. Regardless of these nuanced differences among the two studies, observations of increased abundance, size and biomass of Yellowtail Snapper within the TER, and increased abundance of larger Black and Red Groupers in the Dry Tortugas region indicate that these species are benefiting from the increased protection of DRTO and TER.

In conclusion, the characterization of reef and shelf nekton assemblages in the Tortugas region by CCFHR has provided evidence of several positive impacts on reef fish demography from TER implementation during 2001 through 2005. Observations of these early (i.e., less than 10 years) positive impacts on reef fish assemblages from TER implementation are typical of most marine reserves, but they are still noteworthy given that full recovery of reef fish populations in the area may take decades (Russ et al., 2004).

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Chapter 6: Social and Economic Effects of Ecological Reserves on Commercial Fisheries in Dry Tortugas

Vernon R. Leeworthy[1] and Christopher F.G. Jeffrey[2,3]

INTRODUCTION AND BACKGROUND

This chapter describes and characterizes the human dimensions of Dry Tortugas before and after the implementation of the Tortugas Ecological Reserves (TER). A major goal of this integrated assessment was to determine social and economic consequences, and more specifically, if short-term economic losses occurred to fishers displaced by the reserves. The locations of the no-take reserves in Dry Tortugas were selected to minimize adverse socioeconomic effects, but short-term economic losses to consumptive users still were hypothesized to occur because 391-km^2 of marine waters was closed to commercial and recreational fishing. Two complementary approaches were used by separate teams of social scientists[A] to determine socioeconomic impacts of TER implementation. One team focused on commercial fisheries and conducted statistical analyses of catch landings and revenues reported by fishers before and after TER implementation, as well as the use of *in situ* surveys and monitoring with pre and post spatial distributions of catch. The second team focused on recreational industry and conducted *in situ* surveys of tour guides operating in the Tortugas region before and after TER implementation. Assessments of social and economic impacts of the TER on recreational fisheries are summarized in Chapter 7 of this report.

Although the two teams of social scientists used the findings of Leeworthy and Wiley (2000) as the baseline to determine pre versus post TER impacts, the teams evaluated the commercial and recreational industries differently. The commercial fisheries team took a more quantitative approach that supplemented the baseline data found in Leeworthy and Wiley (2000) with data from several other sources and used five-year pre and post data periods to determine trends in fisheries landings and revenues. Additionally, other factors, including assessments of the biophysical trends, were used to explain observed trends in commercial fisheries. In contrast, the recreation industry team qualitatively evaluated the effects of the TER on recreational activities and purposely did not use quantitative information for pre to post TER comparisons. The recreational team argued that there were too many factors that could explain observed changes in recreational activity and that the quantitative measures could be misinterpreted. Instead, the recreational team conducted *in situ* surveys of charter boat captains that operate in the Tortugas area to determine whether or not the TER affected their businesses.

Marine reserves can have varying levels of socioeconomic impacts on a region depending on the overall condition of the economy. Thus, macroeconomic conditions that determine the overall demand for goods and services should be considered when conducting assessments of the socioeconomic impacts of marine reserves. This chapter (1) summarizes and describes the overall condition of the economy of South Florida and its effect on the demand for goods and services before and after the implementation of the TER; and (2) presents detailed analyses of (a) commercial landings and revenues to fishers reported for Dry Tortugas area between 1997 and 2006, (b) macroeconomic conditions that may have affected revenue streams from commercial fisheries, and (c) the knowledge, perceptions, and attitudes of commercial fishers before and after TER implementation. Analyses of commercial fisheries data excluded areas inside Dry Tortugas National Park (DRTO) because commercial fishing has been prohibited within park boundaries since 1992.

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2. NOAA/NOS/NCCOS/CCMA Biogeography Branch
3. CSS-Dynamac, Fairfax, VA

A. Socioeconomic team was divided into two sub-teams. The Commercial Fisheries Team includes Bob Leeworthy from NOAA's Office of National Marine Sanctuaries, Thomas J. Murray of Thomas J. Murray & Associates, Inc. and the Virginia Institute of Marine Sciences, and Manoj Shivlani from the University of Miami Rosenstiel School of Atmospheric and Marine Sciences. The Recreation Industry Team included David K. Loomis and Christopher Hawkins from the University of Massachusetts Amherst, Douglas Lipton from the University of Maryland, and Robert B. Ditton from Texas A & M University.

MACROECONOMIC CONDITIONS AFFECTING REVENUES FROM DRY TORTUGAS COMMERCIAL FISHERIES AND IMPLICATIONS FOR THE TORTUGAS ECOLOGICAL RESERVES

Condition of Overall Economy

A key factor in assessing the socioeconomic impacts of the TER pre to post establishment is the general condition of the economy. Referred to as macroeconomic conditions, these economic measures could be important factors in determining the demand for goods and services from the Tortugas area and the Florida Keys in general both for the recreation-tourist industry and the commercial fisheries. Sources of demand include both local, state and national areas as well as international areas. Here, a simple look at the macroeconomic conditions in the local Monroe County economy, the state of Florida's economy and the U.S. economy is presented. The changes in real per capita income and real average wages per job (real meaning adjusted for inflation and converted to 2006 dollars) were evaluated. Additionally, changes in unemployment rates were examined; and because the Tortugas is a remote location, diesel fuel prices were also a focus. The pre and post TER periods were defined as two, five-year periods with pre TER including years 1997-2001 and post TER including years 2002-2006. At the time of this assessment, some of the data were not available for 2006.

Measures of Macroeconomic Condition

Real Per Capita Income

The demand for recreation-tourist activities and commercial fishing products may be a function of real per capita income. Real per capita income increased pre to post TER in the U.S., Florida and Monroe County. Real per capita income was higher in Monroe County than either in the entire state of Florida or in the U.S., and increased faster over the entire 1997-2006 period in Monroe County versus the state and the U.S. (Table 6.1). Looking at annual changes, real per capita income declined in 2001, 2002 and 2003 in the U.S. and the state of Florida. Real per capita income declined in 2001 and 2002 in Monroe County, but rebounded in 2003. Given these declines in real per capita income, declines in recreation-tourism demand and the demand for some commercial fishing products like spiny lobsters or shrimp for these years might be expected, holding all other factors constant. Increases in total population, for example, could offset the impact from the decline in real per capita income, and as seen with the commercial shrimp fishery, real prices for shrimp collapsed due largely to increases in imports of shrimp.

Table 6.1. Real per capita income for the U.S., Florida and Monroe County 1997 - 2006.[1]

Year	U.S. (2006 $/Person)	Florida (2006 $/Person)	Monroe County (2006 $/Person)
1997	$31,823	$30,778	$37,267
1998	$33,250	$32,142	$40,317
1999	$33,808	$32,544	$40,439
2000	$34,937	$33,373	$43,321
2001	$34,789	$33,314	$42,287
Pre TER Ave.	**$33,721**	**$32,430**	**$40,726**
2002	$34,508	$33,283	$41,463
2003	$34,476	$33,187	$42,003
2004	$35,315	$34,721	$46,077
2005	$35,581	$35,096	$47,426
2006	$36,272	$35,798	N/A
Post TER Ave.	**$35,230**	**$34,417**	**$44,242**
Post - Pre	**$1,509**	**$1,987**	**$3,516**
Post - Pre % Change	**4.47**	**6.13**	**8.63**

1. Real per capita income is adjusted for inflation using the Consumer Price Index for All Urban Consumers. Per capita income is converted to 2006 dollars.

Real Average Wages Per Job

Over the past two decades, the distribution of income has changed with a marked increase towards those who are in the upper five percent of the income distribution. Trends in real per capita income may have lost some of their meaning for explaining the general demand for goods and services. An alternative measure is the real average wage per job. As with real per capita income, real average wage per job also increased from pre to post TER in the U.S., Florida and Monroe County (Table 6.2). The real average wage per job also increased faster in Monroe County than in the state of Florida or the U.S. However, unlike real per capita income, real average wage per job is lower in Monroe County than in the state of Florida or the U.S. reflecting the lower wage recreation-tourist service sector jobs (see Table 6.2). The general declines in real per capita income

for years 2001, 2002 and 2003 were not as evident in the real average wage per job. The real average wage per job declined in 2001 and 2002 in the U.S. and declined in 2001 in Monroe County, but steadily increased from 1997 to 2006 for the state of Florida.

Unemployment Rates
Another measure for looking at the general state of the macro economy is unemployment rates. The trend in unemployment rates tells a story somewhere between that of real per capita income and real average wage per job. Unemployment rates increased in 2001, 2002 and 2003 corresponding to the declines in real per capita income for the U.S. Unemployment rates increased in 2001 and 2002 for both the state of Florida and Monroe County (Table 6.3).

Diesel Fuel Prices
Much of the for hire recreation industry and the commercial fisheries depend on diesel fuel as a key input of production. The Tortugas area is generally a long way from the home ports of suppliers in both industries. The real prices for diesel fuel increased significantly from pre to post TER. This may have had an impact in the decision to go out to the Tortugas area for both the for-hire recreation-tourist industry operators and the commercial fishing operations. The average real price per gallon of diesel increased 2.0% during the pre TER period and 16.9% over the post TER period (Table 6.4).

Summary of Macroeconomic Conditions
Generally, there was an overall improvement in macro economic conditions pre to post TER. However, the individual years of 2001 and 2002 and sometimes extending into 2003 were generally relatively poor economic times and may have had an impact on recreation-tourist demand and the demand for commercial seafood products.

Table 6.2. Real average wages per job for the U.S., Florida and Monroe County 1997 - 2006.[1]

Year	U.S. (2006 $/Job)	Florida (2006 $/Job)	Monroe County (2006 $/Job)
1997	$37,505	$33,336	$28,510
1998	$38,851	$34,617	$29,911
1999	$39,659	$34,746	$30,379
2000	$40,644	$35,467	$31,261
2001	$40,503	$35,625	$30,764
Pre TER Ave.	**$39,432**	**$34,758**	**$30,165**
2002	$40,509	$36,146	$31,682
2003	$40,724	$36,551	$32,379
2004	$41,400	$37,333	$33,465
2005	$41,439	$37,761	$34,713
2006	N/A.	N/A	N/A
Post TER Ave.	**$41,018**	**$36,948**	**$33,060**
Post - Pre	**$1,586**	**$2,189**	**$2,895**
Post - Pre % Change	**4.02**	**6.30**	**9.60**

1. Real average wage per job is adjusted for inflation using the Consumer Price Index for All Urban Consumers. Average wage per job is converted to 2006 dollars.

Table 6.3. Unemployment rates for the U.S., Florida and Monroe County, 1997-2006.

Year	U.S. Percent	Florida Percent	Monroe County Percent
1997	4.9	5.0	2.4
1998	4.5	4.5	2.7
1999	4.2	4.0	2.3
2000	4.0	3.8	2.9
2001	4.7	4.7	3.4
Pre TER Average	**4.5**	**4.4**	**2.7**
2002	5.8	5.7	3.9
2003	6.0	5.3	3.3
2004	5.5	4.7	3.0
2005	5.1	3.8	2.7
2006	4.6	3.3	2.5
Post TER Average	**5.4**	**4.6**	**3.1**
Post - Pre	**0.9**	**0.2**	**0.3**

Socioeconomic Analysis of Commercial Fisheries in Dry Tortugas

Data Collection, Definition of Study Areas and Statistical Analyses
To assess the impacts of reserves on commercial fisheries, information on fishing effort, costs (fuel prices), landings and ex-vessel revenues were compiled from a variety of sources for the entire Dry Tortugas, Tortugas Ecological Reserve Study Area (TERSA), Monroe County, Florida and the state of Florida. The Dry Tortugas area comprises grid areas 2.0, 2.8 and 2.9 as defined by Florida's Marine Fisheries Institute (FMRI, but here-

after referred to as FWRI in this chapter)[B] for data collection. The TERSA encompasses a 3,503-km^2 (1,020 square mile) area in Dry Tortugas selected by the Florida Keys National Marine Sanctuary (FKNMS) for analyzing five different alternatives, one of which became the TER (Leeworthy et al., 2001). The TERSA excludes the DRTO where commercial fishing has been banned since 1992.

Socioeconomic data for commercial fisheries were compiled at a spatial resolution of 1 nm^2 for reef fishes, spiny lobster (*Panulirus argus*), shrimp, King Mackerel (*Scomberomorus cavalla)* and stone crabs. All data were entered into a GIS and were linked to economic models to estimate the socioeconomic impacts of various no-take area boundaries. In 2000, these data and models were used to predict future potential socioeconomic impacts of various alternatives that were being considered for the no-take areas (Leeworthy and Wiley, 2000).

Table 6.4. Diesel prices, retail prices for the lower Atlantic 1997 - 2006.[1]

Year	CPI: 1982-1984=100[2]	CPI: 2006=1.00	Nominal Price[3]	Real Price[4]	Annual % Increase
1997	160.5	0.7961	112.7	141.6	N/A
1998	163.0	0.8085	101.1	125.0	-11.7
1999	166.6	0.8264	106.8	129.2	3.4
2000	172.2	0.8542	145.0	169.8	31.4
2001	177.1	0.8785	137.1	156.1	-8.1
Pre TER Avg.	**167.9**	**0.8327**	**120.5**	**144.8**	**2.0**
2002	179.9	0.8924	128.0	143.4	-0.9
2003	184.0	0.9127	147.5	161.6	12.7
2004	188.9	0.9370	175.7	187.5	16.0
2005	195.3	0.9688	236.2	243.8	30.0
2006	201.6	1.0000	265.0	265.0	8.7
Post TER Avg.	**189.9**	**0.9422**	**190.5**	**202.2**	**16.9**

1. U.S. Department of Energy, Energy Information Administration. http://www.eia.doe.gov.
2. Consumer Price Index (CPI), All Urban Consumers, U.S. City Average, U.S. Department of Labor, Bureau of Labor Statistics. http://www.bls.gov.
3. Nominal price is not adjusted for inflation. Price is cents per gallon.
4. Real price is adjusted for inflation using the CPI and converting to 2006 dollars. Price is cents per gallon.

Sources of Information

Commercial Fishing Panels: An important source of information for this assessment was the Socioeconomic Research and Monitoring Program for the FKNMS (http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/commercial_fishing/fishing_panels.html). Prior to the implementation of the FKNMS in 1998, the program began collecting baseline socioeconomic data to assess the status of commercial fisheries in the Florida Keys through in-person surveys of commercial fishers organized into four panels, one of which included Dry Tortugas (Table 6.5). The goal of the study was to monitor the impacts of sanctuary regulations on commercial fishers and to assess impacts of the proposed reserves on their fisheries catch and financial performance. Selected participants were representative of the commercial fishers in each location and provided information on total weight of catch by species and grid location, total revenue generated by species, cost of fishing, net earnings from fishing and other related socioeconomic information. Interview surveys were conducted through

Table 6.5. Description of commercial fisher panels surveyed by the Socioeconomic Research and Monitoring Program for the Florida Keys National Marine Sanctuary (FKNMS, http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/commercial_fishing/fishing_panels.html). Survey data were collected through a contract with Thomas J. Murray & Associates, Inc. and a sub-contract with Manoj Shivlani from the University of Miami, Rosenstiel School of Marine and Atmospheric Sciences (UMRSMAS).

Survey Panel	Description
General Fishermen	Fishermen with active saltwater product licenses (SPLs) who did not fish in the Sanctuary Preservation Areas (SPAs) or the Sambos Ecological Reserve (ER) within the FKNMS. Fishermen that fished in Dry Tortugas were excluded from this group because no-take reserves were being considered for that area.
Sambos Fishermen	Fishermen with active SPLs who fished in the Sambos ER prior to July 1997 when the Sambos ER's no-take regulations went into effect.
Tortugas Fishermen	Fishermen with active SPLs who fished in the area generally known as Dry Tortugas (as geographically defined by the Florida Wildlife Research Institute (FWRI) statistical grids 2.0 and 2.9 for gathering information through the trip ticket program).
Marine Life Collectors	Fishermen with active SPLs who report collecting marine species for the aquarium trade.

B. The Florida Marine Research Institute (FMRI) was renamed Florida Fish and Wildlife Research Institute (FWRI) on July 1, 2004.

a contract with Thomas J. Murray & Associates, Inc. and a sub-contract with Manoj Shivlani from the University of Miami, Rosenstiel School of Marine and Atmospheric Sciences (UMRSMAS). A total of eight years of data from fisher interviews (1998-1999 through 2005-2006) were available for this assessment.

Socioeconomic data from the commercial fishing panels for the TERSA hereafter is referred to as microeconomic data. Microeconomic data were collected within two time strata: baseline or pre TER versus post TER to provide detailed synoptic views on individual fishing operations that occurred before the TER, but then were displaced after the reserves were implemented. The baseline microeconomic data were collected for the year July 1, 1998 to June 30, 1999 (1998-1999) while the post TER microeconomic data were collected for the year July 1, 2004 through June 30, 2005.

In contrast, socioeconomic data from commercial fishing panels and other sources for the Tortugas area, Monroe County and state of Florida hereafter are referred to as macroeconomic data. Macroeconomic data are reported in calendar years (January 1 through December 31), thus exact comparisons between macroeconomic and microeconomic data for a given year were not possible.

Additionally, the commercial fishing panels were resurveyed by Thomas Murray and Associates, Inc. and Manoj Shivlani through a Marine Fisheries Initiative grant from the NOAA National Marine Fisheries Service (NMFS).The study included year six of the commercial fishing panels plus a pre versus post comparison of commercial fisheries in the Tortugas region (Thomas J. Murray & Associates, Inc., 2006). Thomas Murray and Manoj Shivlani also replicated a 1995-1996 study on the knowledge, attitudes, and perceptions of regulations and management strategies of the FKNMS (Shivlani et al., 2008). A summary of the data obtained from these studies were also included in this chapter.

<u>State of Florida Trip Ticket Information System:</u> Data on harvest (measured in pounds), exvessel value of landings, and number of fishing trips for total landings by species and area of catch for both Monroe County and the state were obtained from the state of Florida's Trip Ticket Information System on an annual basis.[C] Since 1984, FWRI has been collecting data on commercial fisheries landings and fishing effort. Florida law (Chapters 370.021, .06(2)(a), 370.07(6)(a), and Administrative Code 68E-5.002):

> "...require that all sales of seafood products from the waters of Florida must be reported on a Marine Fisheries Trip Ticket at the time of sale. Trip tickets include information about the harvester, the dealer purchasing the product, the date of the transaction, the county in which the species was landed, time fished and pounds of each species landed for each trip. Completed tickets are mailed to the Florida Fish and Wildlife Conservation Commission, where the data are processed and stored" (http://research.myfwc.com/features/view_article.asp?id=23423).

<u>NMFS Commercial Landings Database:</u> Macroeconomic data on commercial landings and imports of shrimp were obtained from NFMS database of annual commercial landing statistics (NMFS, 2007a,b) to determine overall trends in shrimp landings and imports in the U.S., Gulf of Mexico and Florida (http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html). Data obtained included annual weight and ex-vessel dollar value of landings identified by species. This information was included to help explain annual changes in prices and total revenues received by fishers in the Tortugas during the years before and after implementation of the TER.

<u>Published Studies:</u> Several published reports were reviewed to obtain information on temporal trends in socioeconomic data for the study areas covered by this assessment. The studies reviewed are listed in Table 6.6. The macroeconomic data from Florida's Trip Ticket information for all saltwater product license holders (SPLs) is considered reliable, with only a small subset unreported by area of catch (Leeworthy and Wiley, 2000). Unlike the approach used in the baseline assessment (Leeworthy and Wiley, 2000), the macroeconomic data were used to provide a broader spatial view of the Tortugas area, rather than limiting the analysis to the

C. Catch by area from the FMRI includes statistical grids: 1.0, 1.1, 1.9, 2.0, 2.9, 3.0, 3.1, 3.2, 3.9, 748, 748.1, and 748.9 for Monroe County. The quality of this data has varied over time and improved over the recent past. Most recent data on landings includes 99% of the commercial catch being identified by reporting grid.

Table 6.6. Sources of macroeconomic[1] and microeconomic[2] information used for Tortugas Integrated Assessment.

Fisheries databases
[1] Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute Trip Ticket database. Data summaries were obtained through personal communications with Jim Waters at the NOAA Fisheries, Southeast Fisheries Science Center. This was required because we were not allowed access directly to the "trip ticket" database because of rules to protect the proprietary nature of the data.
[1] National Marine Fisheries Service (NMFS). 2007b on-line database of commercial fishing statistics. http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html.
Published Reports
[1,2] Leeworthy, Vernon R. and Wiley, Peter C. 2000. Proposed Tortugas 2000 Ecological Reserve: Final Socioeconomic Impact of Alternatives. National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects, Silver Spring, MD. October 2000, pp.157. http://coastalsocioeconomics.noaa.gov/core/reserves/tortugas.pdf.
[1] National Marine Fisheries Service (NMFS). 2007a. Fisheries of the United States, 2006. Current Fishery Statistics No. 2006. Office of Science and Technology, Fisheries Statistics Division, Silver Spring, MD. July 2007, pp. 119.
[2] Shivlani, Manoj and Tonioli, Flavia. 2007. 2003-04 and 2004-05 Florida Keys National Marine Sanctuary Commercial Fishing Panels' Spatial Fishery Profiles. April 4, 2007, pp.36. http://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/1812/fknms_commercial_fish_panel_spatial_profile_2003-05.pdf.
[2] Thomas J. Murray & Associates, Inc. 2006. Tortugas 2000 – A Post Mortem: Evaluation of Actual versus Projected Socioeconomic Impacts of the Dry Tortugas Ecological Reserve, Final Report. Report under MARFIN Grant NA04NMF4330079, December 31, 2005, Revised May 2006, pp.31. http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/pdfs/tortugasmarfin.pdf
[2] Thomas J. Murray & Associates, Inc. 2007. Socio-economic Baseline Development Florida Keys National Marine Sanctuary: Years 1998-2006. Commercial Fishing Panels. June 30, 2007, pp27. http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/pdfs/commfishpan7and8.pdf.
[2] Shivlani, M., Leeworthy, V.R., Murray, T.J., Suman, D.O., and Tonioli, F. 2008. Knowledge, Attitudes and Perceptions of Management Strategies and Regulations of the Florida Keys National Marine Sanctuary by Commercial Fishers, Dive Operators and Environmental Group Members: A Baseline Characterization and 10-year Comparison. Marine Sactuaries Conservation Series ONMS-08-06. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 170 pp. http://sanctuaries.noaa.gov/science/conservation/pdfs/kap2.pdf
1. Source of macroeconomic data; 2. Source of microeconomic data

TERSA. This broader perspective allowed assessment of any shifts in fishing grounds used by fishers and any substitution across the species occurred.

The original baseline study, which was based on data from 1997, predicted several potential socioeconomic impacts of the TER (Leeworthy and Wiley, 2000). A longer time series would have been preferable, but that was not possible because catch data reported in the Florida Trip Ticket database prior to 1997 contained incomplete information about the grid-location of catch. In 1994, only about one-third of all catch was reported by grid area. Reporting of catch by area improved to about 63% in 1995, to 96.3% in 1996 and to 99.9% in 1997. Overall, 1997 was a relatively good year for the commercial fisheries in Florida. Thus it was expected that any projections of impact might be overestimated.

The macroeconomic data were also used to track individual SPLs to determine the distributions of economic impact among fishers and to assess dependency of fishers on the Tortugas fishing grounds relative to other fishing grounds. This approach addressed both spatial and inter-species substitution by fishers in the region, who mostly fish for multiple species in multiple fishing grounds.

The macroeconomic data were supported with the microeconomic data from several of the surveys noted above to provide additional details about the economic impacts on individual fishing operations that were displaced by the TER. The microeconomic dataset included detailed information on harvest; costs-and-earnings; investment in boats and equipment, spatial distribution of catch, and demographic profiles of the fishermen. It also contained information fishers' knowledge, attitudes, and perceptions of regulations and management strategies in the FKNMS. Full citations for the publications used in the analysis of the microeconomic data are listed in Table 6.6.

Results and Discussion

Overall Characterization of Commercial Fisheries

Number of Fishing Operations or SPLs: The total number of fishing operations, as measured by the number of SPLs, fishing in the Tortugas areas (FWRI areas 2.0, 2.8 and 2.9) has fluctuated over the 1997-2006 period, but overall there has been a downward trend. This is consistent with the trends in the entire state of Florida. The average number of SPLs fishing in the Tortugas region declined by about 12% from 601 SPLs during the pre TER period to 531 SPLs during the post TER period. The decline in the number of SPLs was less during the post TER period than during the pre TER period. During the pre TER period, the number of SPLS declined by 37%, while during the post TER period, the decline was 2.18% (Table 6.7).

Table 6.7. Number of saltwater product licenses (SPLs) pre versus post TER.

Year	SPLs	Change in SPLs	% Change in SPLs
1997	657	-	-
1998	665	8	1.22
1999	597	-68	-10.23
2000	529	-68	-11.39
2001	556	27	5.10
Pre TER Average	**601**	**-101**	**-15.37**
2002	504	-52	-9.35
2003	543	39	7.74
2004	567	24	4.42
2005	546	-21	-3.70
2006	493	-53	-9.71
Post TER Average	**531**	**-11**	**-2.18**

Dependence on the Tortugas Area: Fishing in the Tortugas area appeared to be opportunistic. Many of SPLs holders, who entered and exited the commercial fishery, caught very little within the Tortugas and may not have been heavily dependent on that area for their fishing revenues. In the pre TER period, 1,436 different SPL holders fished the Tortugas area during 1997 to 2001 (Table 6.8). Twenty-six percent of these SPLs received 79% of the total ex-vessel revenues from the Tortugas area (Table 6.8). This ratio is very close to the 20-80 rule of thumb found to characterize most commercial fisheries, i.e. that 20% of the fishermen catch 80% of the fish.

Table 6.8. Distribution of average revenues for all Tortugas fishermen: pre TER (1997-2001).

Ex-vessel Value of Catch	Number of SPLs	% of SPLs	Sum of Avg. Revenues	Percent of Revenues
GT $0	1,436	100.0	$62,677,154	100.0
GE $250,000	38	2.6	$11,660,897	18.6
GE $100,000	190	13.2	$36,493,437	58.2
GE $50,000	373	26.0	$49,567,073	79.1
GE $20,000	622	43.3	$57,806,282	92.2
LT $20,000	814	56.7	$3,967,282	6.3
LT $5,000	530	36.9	$805,508	1.3
LT $1,000	257	17.9	$98,509	0.2

NOTE: GT=Greater than, GE=Greater than or Equal to, LT=Less than; Average ex-vessel revenue was $43,019.

Table 6.8 shows the distribution of revenues received by SPLs across all species caught in the Tortugas areas for the pre TER period. Almost 57% of the SPLs accounted for only 6.3% of the revenues and each of these SPLs received less than $20,000 in total revenue per year over the pre TER period from their catch in the Tortugas area. Almost 18% of SPLs caught less than $1,000 worth of fish and shellfish from the Tortugas area, which represents only a fraction of one percent of the total revenues received by SPLs from catch in the Tortugas area. Only 26% of SPLs received more than $50,000 per year and only 13.2% received $100,000 per year, so the overwhelming majority of SPLs are not highly dependent on the Tortugas area alone for their fishing revenues.

In the post TER period, the number of SPLs fishing in the Tortugas area declined by 299 (21%) from a pre TER level of 1,436 to 1,137 in the post TER period. The distribution of revenues received by SPLs was not much different between pre and post TER, but there was slightly more dependency in the post TER period with a greater proportion of SPL holders having received $50,000 to $100,000 or more in fishing revenues from the Tortugas area (Table 6.9). The overall average ex-vessel revenue received by SPL holders increased from $43,019

in the pre TER period to $47,733 in the post TER period or about a 10% increase. This increase was not adjusted for inflation.

Table 6.9. Distribution of average ex-vessel revenues for all Tortugas fishermen: post TER (2002-2006).

Ex-vessel Value of Catch	Number of SPLs	% of SPLs	Percent of Revenues
GT $0	1,137	100.0	100.0
GE $250,000	27	2.2	15.4
GE $100,000	176	15.4	57.4
GE $50,000	348	30.5	80.0
GE $20,000	579	50.8	94.0
LT $20,000	558	49.2	6.0
LT $5,000	319	28.2	1.0
LT $1,000	120	10.5	0.1

NOTE: GT=Greater than, GE=Greater than or Equal to, LT=Less than; Average ex-vessel revenue was $43,019.

Another way of measuring a change in the dependence of SPL holders on the Tortugas area is to determine whether any change occurred in the spatial distribution of fishing revenues for SPL holders that fished in the Tortugas. Before implementation of the TER, SPL holders that fished in the Tortugas area derived 28.87% of their total fishing revenues from the area (Table 6.10). These fishers increased the proportion of their revenues derived from the Tortugas region to 31.04% after the TER was implemented. The increase in revenues from the Tortugas was accompanied by a decrease in fishing revenues from other areas such as Key West and "other Florida" areas. The spatial shift toward increased dependence on the Tortugas for additional fishing revenues was true across all species and for each species/species group for which fishing was prohibited. The King Mackerel fishery experienced the largest spatial shift in revenue after the TER was implemented. During the pre TER period, SPL holders received only 26.41% of their King Mackerel fishing revenues from the Tortugas compared with 56.77% during the post TER period. Thus, SPL holders that fished the Tortugas subsequently became more dependent on that area for their fishing revenues after implementation of the reserve.

Table 6.10. Distributions of revenues of catch by species/species groups and waterbodies: pre versus post TER.

Species/ Period	Waterbodies (Percent of Catch)									
	Tortugas	Key West	Marathon	Everglades	Miami	Ft. Myers	Tampa	Other FL	Other States	Unknown
Reef Fish										
Pre	17.10	12.85	0.83	7.95	2.14	13.98	31.01	13.25	0.12	0.76
Post	18.69	7.76	1.39	8.99	1.79	18.50	27.90	14.65	0.13	0.20
Spiny Lobster										
Pre	39.84	44.92	7.72	3.65	1.98	1.31	0.02	0.45	0.00	0.10
Post	48.91	35.30	10.51	2.57	2.04	0.27	0.02	0.38	0.00	0.00
Shrimp										
Pre	37.78	3.75	0.03	3.36	0.02	9.02	7.23	37.22	1.58	0.01
Post	39.87	1.70	0.01	2.24	0.03	13.72	8.79	31.89	1.74	0.001
King Mackerel										
Pre	26.41	42.57	0.60	11.51	0.66	0.07	0.19	17.92	0.06	0.002
Post	56.77	21.07	0.24	7.00	0.52	0.57	0.04	13.72	0.08	0.00
Stone Crab										
Pre	2.99	29.27	8.43	44.86	1.37	4.79	0.90	0.86	0.00	0.05
Post	6.63	26.97	11.04	49.86	0.52	2.76	1.02	1.20	0.00	0.01
Non Reef Fish[1]										
Pre	10.77	14.72	1.33	6.32	1.95	2.81	5.77	51.82	2.20	2.30
Post	24.49	8.61	3.29	3.93	0.99	4.61	8.30	34.71	6.61	4.46
All Species										
Pre	28.87	14.38	2.18	7.64	0.89	7.54	8.79	28.33	1.03	0.34
Post	31.04	10.97	3.26	9.13	0.84	10.82	10.86	21.09	1.47	0.51

1. Non reef fish include all non reef fish, excluding King Mackerel.

The shift demonstrates the spatial substitution referenced in Leeworthy and Wiley (2000) in their baseline assessment and projection of the potential socioeconomic impact of the TER. Even in the face of displacement from the TER, a higher proportion of fishing revenues were derived from the Tortugas area not less as would have been expected if the TER had a negative short-term impact on the commercial fisheries. This issue will be examined further to determine what happened to the total amount of revenues derived from the Tortugas pre versus post TER.

Changes in Total Ex-vessel Revenues Pre and Post TER: The amount of revenues that fishermen receive for their catch is called ex-vessel revenues. Ex-vessel revenues are equal to the pounds of fish and/or shellfish landed multiplied by the price per pound. Total ex-vessel revenues from all catch in the Tortugas area declined from pre to post TER. Almost the entire decline was due to the decline in the price of shrimp, which accounted for, on average, 67% of total ex-vessel revenues from catch in the Tortugas area in the pre TER period and 55% in the post TER period (Table 6.11). There was an increase in revenues from reef fish, King Mackerel, stone crabs and all other species. Declines were experienced in spiny lobster as well (Table 6.12).

Table 6.11. Total ex-vessel value of landings Tortugas areas 1997-2006.

Year	All Species Nominal Value (Millions $)	All Shrimp $ Nominal Value (Millions $)	% Shrimp of Total	All Species Real Value (Millions 2006 $)	All Shrimp Real Value (Millions 2006 $)
1997	$32.5	$24.2	74.5	$40.82	$30.40
1998	$32.5	$23.8	73.2	$40.20	$29.44
1999	$25.1	$14.9	59.4	$30.37	$18.03
2000	$22.2	$12.8	57.7	$25.99	$14.99
2001	$24.6	$16.1	65.4	$28.00	$18.33
1997-2001	**$137.0**	**$91.8**	**67.0**	**$164.52**	**$110.24**
2002	$19.9	$12.6	63.3	$22.30	$14.12
2003	$21.4	$13.1	61.2	$23.45	$14.35
2004	$25.8	$14.3	55.4	$27.53	$15.26
2005	$22.9	$11.5	50.2	$23.64	$11.87
2006	$28.7	$13.9	48.4	$28.70	$13.90
2002-2006	**$118.7**	**$65.4**	**55.1**	**$125.99**	**$69.41**

The decline in shrimp prices explains almost all the decline in ex-vessel revenues received from catch from the Tortugas. Prices received for Tortugas-caught shrimp declined from an average real price (adjusted for inflation to 2006 dollars) of $4.30 per pound pre TER to $2.36 per pound post TER (Table 6.12). Although shrimp caught in the Tortugas fetched higher real prices per pound than shrimp caught commercially in the Gulf of Mexico and elsewhere in U.S., the same pattern of declines were evident for the entire shrimp commercial fishery in the U.S.

Table 6.12. Total ex-vessel revenues by species/species group for pre and post TER for all tortugas areas.

	Pre TER Ex-vessel Revenues	Post TER Ex-vessel Revenues	Post - Pre Ex-vessel Revenues
Species/Species Groups	2006 $	2006 $	2006 $
All Species	$164,542,407	$126,008,487	-$38,533,920
Reef Fish	$14,086,203	$16,527,873	$2,441,670
Spiny Lobster	$31,201,871	$25,681,579	-$5,520,292
King Mackerel	$1,714,706	$3,588,489	$1,873,783
Shrimp	$110,231,017	$69,466,015	-$40,765,002
Stone Crab	$1,386,932	$2,949,013	$1,562,081
All Other	$5,939,880	$7,691,057	$1,751,177

NOTE: Pre TER (1997-2001) and post TER (2002-2006).

The declines in shrimp prices may have been caused by an increase in the supply of imported shrimp. In 1997, U.S. commercial landings of shrimp were a little over 179 million pounds, while imports were about 811 million pounds. By 2006, U.S. commercial landings had only increased to 182 million pounds, while imports increased to over 1.7 billion pounds (NMFS, 2007a).

It will become evident in the report as each fishery is addressed that even though ex-vessel revenues from shrimp caught in the Tortugas decline pre to post TER, actual pounds of shrimp catch increased pre to post TER.

As noted above, not all fisheries in the Tortugas area were characterized by declines in total ex-vessel revenues from pre to post TER periods. Many SPL holders that fish in the Tortugas fish for multiple species/species groups, and it is possible that losses from targeting one fishery species could have been off-set by gains from another fishery species. The changes in total ex-vessel revenues received by each SPL holder that fished in the Tortugas area during the pre and post TER periods were calculated. Overall 558 SPL holders fished in the Tortugas area in both the pre and post TER periods (Table 6.12). Of these, 303 SPL holders (54.3%) lost revenues, while 255 (44.7%) increased revenues after the TER was implemented. On average, SPL holders suffered an overall decline in total ex-vessel revenues of $7,931 with a median loss of $580 from their catch in the Tortugas. The largest loss was $344,719 by a shrimper. However, there were SPL holders that also experienced increases in ex-vessel revenues; one shrimper gained $369,243 after the reserve was implemented (Table 6.13).

Table 6.13. Distribution of the change in ex-vessel revenues able for all Tortugas fishermen for all species post - pre TER.

Change in Ex-vessel Revenue[1]	Number of SPLs	Percent of SPLs
Decreases in Revenues		
$300,000 +	2	0.4
$200,000 - $299,999	11	2.0
$100,000 - $199,999	36	6.4
$50,000 - $99,999	60	10.8
$25,000 - $49,999	47	8.4
$10,000 - $24,999	52	9.3
$5,000 - $9,999	27	4.8
$1 - $4,999	68	12.2
Greater than $0	303	54.3
Increases in Revenues		
Greater than $0	255	45.7
$1 - $4,999	66	11.6
$5,000 - $9,999	29	5.1
$10,000 - $24,999	46	8.1
$25,000 - $49,999	41	7.1
$50,000 - $99,999	44	7.7
$100,000 - $199,999	21	3.8
$200,000 - $299,999	7	1.1
$300,000 +	1	0.2

1. Mean= -$7,931; Median=-$580; Min=-$344,719; Max=+$369,243; Standard error=+ $3,161; N=558.

Essentially for every fisher that lost revenue, one gained revenue. Excluding the losses in the shrimp fishery, there was an overall increase in ex-vessel revenues from catch in the Tortugas area during the post TER relative to the pre TER period. Thus, from this perspective it appears there were no short-term losses to the commercial fisheries caused by establishing the TER. In addition, some hypothesized that fishing congestion would result from displaced fishermen crowding into the remaining open areas in the Tortugas region. The overall decline in the number of SPL holders in the Tortugas region and other parts of Florida, however, suggests that congestion effect did not occur. A reduction in the number of SPLs may overestimate the loss in fishing effort because the microeconomic data on species-specific fishing effort indicate that vessels and equipment may have been consolidated among the remaining SPL holders in the fishery. However, even with this consolidation, total effort has decreased, and the macroeconomic data did not reveal congestion effects except in the spiny lobster fishery.

The remaining sections of this chapter will address this in more detail with focus on each species/species group and will incorporate the microeconomic data. The species/species group macro and microeconomic data were used to examine the pounds of catch, as well as vessel revenues. As a result, it was possible to integrate the assessment results with the physical science data on how stocks of fish and invertebrates have fared in the pre and post TER periods.

Reef Fish Fishery

Leeworthy and Wiley (2000) predicted that reef fisheries in the Tortugas would likely suffer short-term losses caused by congestion effect. However, a comparison of data on reef fish catch and fishing effort before and after implementation of the TER does not support this prediction.

Reef Fish Fishery Macroeconomic Data: Overall, the total catch of reef fish from the Tortugas areas increased from about 5.9 million pounds during the pre-TER period to over 6.8 million pounds during the post-TER period (Table 6.14). The best three years between 1997 and 2006 occurred in the post TER period from 2004-2006. In addition, the real value (adjusted for inflation) of ex-vessel revenues increased as real prices increased slightly from pre to post TER.

Table 6.14. Catch, landings, ex-vessel value and prices for Tortugas Reef.

Year	Caught/Landed	Pounds	Nominal[1] Value ($)	Nominal Price ($/lb)	Real Value[2] (2006 $)	Real Price (2006 $/lb.)
1997-2006	**All Tortugas-Catch**	**12,686,493**	**$27,378,622**	**$2.16**	**$30,614,076**	**$2.41**
1997-2006	**Monroe County Landed**	**10,121,587**	**$21,784,834**	**$2.15**		
1997	All Tortugas	1,160,087	$2,243,965	$1.93	$2,818,697	$2.43
1998	All Tortugas	1,202,454	$2,401,786	$2.00	$2,970,669	$2.47
1999	All Tortugas	1,324,467	$2,632,637	$1.99	$3,185,669	$2.41
2000	All Tortugas	1,011,549	$2,058,732	$2.04	$2,410,129	$2.38
2001	All Tortugas	1,158,311	$2,372,862	$2.05	$2,701,038	$2.33
5-year	**Pre- Total**	**5,856,868**	**$11,709,982**	**$2.00**	**$14,086,203**	**$2.40**
2002	All Tortugas	1,115,238	$2,300,651	$2.06	$2,578,049	$2.31
2003	All Tortugas	1,187,959	$2,479,014	$2.09	$2,716,132	$2.29
2004	All Tortugas	1,637,791	$3,610,665	$2.20	$3,853,431	$2.35
2005	All Tortugas	1,355,518	$3,165,661	$2.34	$3,267,610	$2.41
2006	All Tortugas	1,533,119	$4,112,650	$2.68	$4,112,650	$2.68
5-year	**Post - Total**	**6,829,625**	**$15,668,641**	**$2.29**	**$16,527,873**	**$2.44**
	Post - Pre	**972,757**	**$3,958,659**	**$0.29**	**$2,441,670**	**$0.04**
3 years	**Best Three Years - Pre**	**3,687,008**	**$7,278,388**	**$1.97**	**$8,975,036**	**$2.43**
3 years	**Best Three Years - Post**	**4,526,428**	**$10,888,976**	**$2.41**	**$11,233,692**	**$2.48**
	Post - Pre (Best 3 Years)	**839,420**	**$3,610,588**	**$0.43**	**$2,258,656**	**$0.05**

1. Nominal ex-vessel value and prices are not adjusted for inflation.
2. Real ex-vessel value and prices are adjusted for inflation using the Consumer Price Index for All Urban Consumers. Ex-vessel value and prices are converted to 2006 dollars.

<u>Dependence on the Tortugas Areas:</u> During the pre TER period, 608 SPLs fished in the Tortugas areas. That number declined to 471 SPLs during the post TER period. In the pre TER period only four SPLs (0.5%) caught 50,000 or more pounds in the Tortugas areas (Table 6.15), while nine SPLs (1.7%) caught 50,000 or more pounds in the post TER period (Table 6.16). In the pre TER period, 22.5% of the SPLs that fished in the Tortugas areas caught 80.8% of the catch. This is close to the 20-80 rule often cited in other fisheries throughout the country. In the post TER period, 20.4% of the SPLs that fished in the Tortugas areas caught 77.9% of the total catch. The average pounds of catch per SPL were 4,414 pre TER and increased to 6,564 post TER. Generally, fewer SPL holders were catching more reef fish per SPL pre to post TER.

Table 6.15. Distribution of average pounds of catch for all Tortugas reef fish fishermen: pre TER (1997-2001).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Pounds
GT 0	608	100.0	100.0
GE 50,000	4	0.5	9.5
GE 25,000	23	3.6	32.8
GE 10,000	80	13.0	65.1
GE 5,000	138	22.5	80.8
LT 5,000	470	77.5	19.2
LT 1,000	310	51.0	3.6
LT 500	231	38.0	1.4
LT 100	100	16.4	0.20

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 4,414, with min=6 and max=86,996.

Table 6.16. Distribution of average pounds of catch for all Tortugas reef fish fishermen: post TER (2002-2006).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Pounds
GT 0	471	100.0	100.0
GE 50,000	9	1.7	20.0
GE 25,000	34	7.0	47.5
GE 10,000	97	20.4	77.9
GE 5,000	141	29.7	88.3
LT 5,000	330	70.3	11.7
LT 1,000	204	43.3	2.0
LT 100	63	13.4	0.1

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 6,564 with min=1.0 and max=113,678.

The distribution of ex-vessel revenues tells the same story as the distribution of pounds of catch. Few would seem to rely on reef fish catch from the Tortugas. In the commercial fishing panels (Thomas J. Murray & Associates, Inc., 2007), full-time fishermen had total fishing revenues ranging from $80,000 to $215,000 per year. Very few reef fish fishermen in the Tortugas earned enough from fish caught in the Tortugas to be full-time fishermen (Tables 6.17 and 6.18). Only 0.5% of SPLs received $100,000 or more in revenue from reef fish catch in the Tortugas in the pre TER period, while 1.7% of SPLs received $100,000 or more from their reef fish catch in the Tortugas in the post TER period. Overall, average revenues per SPL from reef fish in the Tortugas increased from $8,974 during the pre TER period to $15,125 during the post TER period.

Table 6.17. Distribution of average revenues for all Tortugas reef fish fishermen: pre TER(1997-2001).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	608	100	100
GE $100,000	4	0.5	9.5
GE $50,000	25	4.9	34.8
GE $20,000	81	13.3	65.9
LT $20,000	527	86.7	34.1
LT $5,000	398	65.5	9.1
LT $1,000	236	38.8	1.4
LT $500	169	27.8	0.5
LT $100	67	11	0.06
LT 100	63	13.4	0.1

1. GT=Greater than; GE=Greater than of Equal to; LT=Less than
2. Average revenues per SPL was equal to $8,974 with min=$10 and max=$155,951.

The spatial distribution of reef fish catch by species groups across South Florida also supports the hypothesis that there were no short-term losses as a result of the TER. Reef fishermen that fished in the Tortugas areas caught 18.14% of their reef fish in the Tortugas areas in the pre TER period and 18.84% in the post TER period (Table 6.19).

All the macroeconomic data shows that reef fish fishers have become more dependent on the Tortugas areas pre to post TER. Fewer SPLs catching both more per SPL and more in aggregate (total pounds of catch) would also indicate that the congestion effect was not experienced as projected in Leeworthy and Wiley (2000). Thus, from the macroeconomic data, there is no evidence that short-term losses have occurred as a result of the TER.

Table 6.18. Distribution of average revenues for all Tortugas reef fish fishermen: post TER (2002-2006).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	471	100.0	100.0
GE $100,000	9	1.7	21.5
GE $50,000	41	8.3	54.0
GE $20,000	99	21.0	79.9
LT $20,000	372	79.0	20.1
LT $5,000	279	59.2	5.4
LT $1,000	152	32.3	0.7
LT $500	103	21.9	0.3
LT $100	34	7.2	0.03

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average Revenue per SPL was equal to $15,125 with min=$2.20 and max=$317,334.

<u>Reef Fishery Microeconomic Data:</u> The microeconomic data from Thomas J. Murray & Associates, Inc. (2006) reports snap shot pictures of the Tortugas fishery for years 1998-1999 (pre TER) and 2004-2005 (post TER). The TERSA is used for the Tortugas area which is more limited than that used in the macroeconomic data, but it does include the wider area of the FKNMS and the Gulf of Mexico. The microeconomic data show that fewer SPLs were fishing in the TERSA pre to post TER. This is consistent with the macroeconomic data for the larger Tortugas areas. Also, the microeconomic data show that there has been a consolidation of vessels and equipment with a smaller number of SPLs with a lot more vessels and equipment per SPL pre to post TER. Average trip days put on an SPL and vessel basis both declined as well, indicating an overall effort declined. With both the decline in number of SPLs and trip days per SPL, total reef fishery effort declined. Average landings increased from 21,705 lbs per SPL in 1998-1999 (pre TER) to 23,700 pounds per SPL in 2004-2005 (post TER). This again is consistent with the macroeconomic data for all the Tortugas area.

Table 6.19. Distributions of pounds of catch by species/species groups and water bodies: pre versus post TER.

Species/ Period	Waterbodies (Percent of Catch)									
	Tortugas	Key West	Marathon	Everglades	Miami	Ft. Myers	Tampa	Other FL	Other States	Unknown
Reef Fish										
Pre	18.14	13.81	0.78	7.77	2.87	13.04	29.66	13.06	0.11	0.77
Post	18.84	8.50	1.76	8.62	2.39	17.91	27.04	14.59	0.14	0.20
Spiny Lobster										
Pre	38.80	46.52	7.42	3.60	1.87	1.31	0.01	0.37	0.00	0.11
Post	49.04	35.78	10.04	2.53	1.93	0.29	0.02	0.36	0.00	0.00
Shrimp										
Pre	34.04	4.28	0.05	2.48	0.04	6.56	5.88	45.12	1.52	0.02
Post	40.77	2.30	0.02	1.83	0.07	10.13	5.58	37.76	1.54	0.002
King Mackerel										
Pre	30.56	43.84	0.75	13.44	0.49	0.05	0.15	10.69	0.03	0.002
Post	64.99	18.29	0.19	7.66	0.40	0.29	0.03	8.09	0.06	0.00
Stone Crab										
Pre	3.46	35.07	8.64	44.70	1.12	5.00	0.91	1.04	0.00	0.05
Post	5.97	26.58	10.81	51.19	0.46	2.71	1.09	1.18	0.00	0.01
Non Reef Fish										
Pre	13.14	16.85	0.99	10.12	1.51	3.16	6.48	45.23	1.50	1.04
Post	22.84	9.79	1.88	5.67	2.13	4.57	7.32	40.77	3.07	1.96

On the issue of dependence on the Tortugas, with the limited definition of the Tortugas, dependence on the TERSA declined from 48.1% of reef fish catch in 1998-1999 (pre TER) to 42.9% of reef fish catch in 2004-2005 (post TER). This is not consistent with the macroeconomic data for the Tortugas areas. For capturing spatial substitution, a wider view, as in the macroeconomic data is required.

The microeconomic data also show that fuel expenditures increased significantly, which would have decreased net earnings. Average costs of fuel per trip more than doubled from 1998-1999 (pre TER) to 2004-2005 (post TER) for reef fish fishermen who fished in the TERSA. The real price of diesel fuel for the lower Atlantic increased from a pre TER average of $1.448 per gallon to $2.022 per gallon post TER (U.S. Dept. of Energy, 1997-2006). The distribution of reef fish catch shows that reef fishermen moved to fishing waters closer to the port of Key West in the proportion of their total reef fish catch. This was probably in response to the higher fuels costs.

As with the macroeconomic data, there is no evidence that there were short-term losses to the reef fish fishermen that fished in the Tortugas because of the TER. Even though the macro and microeconomic data show increases in catch and revenues to Tortugas fishermen, it cannot be concluded that the TER was a benefit in the short-term. As was maintained by the biologists in their assessment of the TER, reef fish are too slow growing for the TER to have an effect in the short pre-post comparison presented here. The microeconomic data would seem to supply an explanation.

Thomas J. Murray & Associates, Inc. (2006), developed detailed maps of the distributions of reef fish catch both pre and post TER. When the TIA team of social scientists and biologists met to compare information, the biologists noted that the maps of commercial catch generated by Thomas J. Murray & Associates, Inc. showed that fishermen had shifted to areas that were not being sampled by reef fish biologists. These maps showed that the displacement from the TER had resulted in fishermen visiting areas they never fished before. This explains the discrepancy between the biological assessment of overfishing for reef fish and the macro and microeconomic data showing increases in reef fish catch. What the macro and microeconomic data are showing is the “expansionary phase” of a new fishery. Again, spatial substitution has resulted in mitigating/off-setting any losses from displacement from the TER for the reef fish fishery.

Spiny Lobster Fishery

Leeworthy and Wiley (2000), projected that there would be no short-term negative impact of the TER on the spiny lobster fishery. One of the key factors behind this assessment was the spiny lobster trap reduction program, which intended to reduce the number of lobster traps by 10% per year. A 10% reduction in traps would have made it possible for those who were displaced from the TER to relocate to other fishing spots and avoid the congestion effects of displacement. However, the trap reduction program was put on hold. In addition, hurricanes and disease negatively affected spiny lobster stocks (Ehrhardt, 2005; Johnson et al., 2007) and caused a lagged effect on catch between 2001 and 2003, just before the TER went into effect and for two years after the TER went into effect (Table 6.20).

<u>Spiny Lobster Fishery Macroeconomic Data:</u> Spiny lobster catch from all the Tortugas areas declined from about 5.8 million pounds during the pre-TER years to about 5.1 million pounds during post TER years. As mentioned above, the decline started in the last year pre TER and continued through 2003 (Table 6.20). The spiny lobster fishery in the Tortugas areas began to recover in 2004. A comparison of the best three years of catch before and after TER was implemented show that the losses in catch were about 176,000 lbs. Additionally, overall catch and real value of spiny lobster have been increasing since 2002, with 2006 being the best year since 1997.

When looking at overall ex-vessel revenues received by Tortugas fishers who fished for lobsters, the losses were magnified because real prices received for spiny lobster declined between 1999 and 2005 (Table 6.20). The increase in fuel prices coupled with decreased prices for spiny lobsters, synergistically reduced net revenues for fishers in the Tortugas region.

*Table 6.20. Catch, landings, ex-vessel value, and prices for Tortugas spiny lobster (*Panulirus argus*): pre versus post TER.*

Year	Caught/Landed	Pounds	Nominal[1] Value ($)	Nominal Price ($/lb)	Real Value[2] (2006 $)	Real Price (2006 $/lb.)
1997-2006	**All Tortugas-Catch**	**10,933,392**	**$50,178,468**	**$4.59**	**$56,883,450**	**$5.20**
1997-2006	**Monroe County Landed**	**10,861,224**	**$49,801,406**	**$4.59**		
1997	All Tortugas	1,186,567	$4,724,318	$3.98	$5,934,327	$5.00
1998	All Tortugas	1,080,453	$4,272,516	$3.95	$5,284,497	$4.89
1999	All Tortugas	1,281,549	$5,819,367	$4.54	$7,041,828	$5.49
2000	All Tortugas	1,343,910	$6,632,576	$4.94	$7,764,664	$5.78
2001	All Tortugas	934,243	$4,533,021	$4.85	$5,159,956	$5.52
5-year	**Pre- Total**	**5,826,722**	**$25,981,798**	**$4.46**	**$31,201,871**	**$5.35**
2002	All Tortugas	716,121	$3,352,111	$4.68	$3,756,288	$5.25
2003	All Tortugas	754,142	$3,204,614	$4.25	$3,511,136	$4.66
2004	All Tortugas	1,171,245	$5,012,086	$4.28	$5,349,078	$4.57
2005	All Tortugas	1,047,312	$4,951,460	$4.73	$5,110,921	$4.88
2006	All Tortugas	1,417,850	$7,676,399	$5.41	$7,676,399	$5.41
5-year	**Post - Total**	**5,106,670**	**$24,196,670**	**$4.74**	**$25,681,579**	**$5.03**
	Post - Pre	**-720,052**	**-$1,785,128**	**$0.28**	**-$5,520,292**	**-$0.33**
3 years	**Best Three Years - Pre**	**3,812,026**	**$17,176,261**	**$4.51**	**$20,740,820**	**$5.44**
3 years	**Best Three Years - Post**	**3,636,407**	**$17,639,945**	**$4.85**	**$18,136,398**	**$4.99**
	Post - Pre (Best 3 Years)	**-175,619**	**$463,684**	**$0.35**	**-$2,604,422**	**-$0.45**

1. Nominal ex-vessel value and prices are not adjusted for inflation.
2. Real ex-vessel value and prices are adjusted for inflation using the Consumer Price Index for All Urban Consumers. Ex-vessel value and prices are converted to 2006 dollars.

Table 6.21. Distribution of average pounds of catch for all tortugas spiny lobster fishermen: pre TER (1997 - 2001).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Pounds
GT 0	332	100.0	100.0
GE 50,000	8	2.1	22.7
GE 25,000	33	9.6	61.9
GE 15,000	51	15.1	78.3
GE 10,000	65	19.9	78.9
GE 5,000	84	25.0	92.5
LT 5,000	248	75.0	7.5
LT 1,000	195	58.7	1.6
LT 500	168	50.6	0.8
LT 100	106	31.9	0.2

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 6,829 with min=1.0 and max=94,319.

Dependence on the Tortugas Areas: The number of SPLs fishing for spiny lobsters in the Tortugas areas declined from 332 in the pre TER period to 316 in the post TER period. This follows the trends throughout Florida and Monroe County (Thomas J. Murray & Associates, Inc., 2007). Again, the 20-80 rule seems to characterize the Tortugas spiny lobster fishery, with 19.9 of the SPLs accounting for 78.9% of the catch in the pre TER period and 20.3% of the SPLs accounting for 78.2% of the catch in the post TER period. Eight SPLs caught 50,000 lbs or more in the pre TER period and this declined to seven SPLs in the post TER period (Tables 6.21 and 6.22). The average catch per SPL was 6,829 lbs in the pre TER period and 6,760 lbs in the post TER period.

The distributions on ex-vessel revenues tell a similar story as catch. Using the $100,000 in revenue as defining a full-time fisherman, in the pre TER period 10.8% of SPLs were full-time fishermen, while this declined to 9.8% in the post TER period. The average SPL received $30,518 in the pre TER period and $32,449 in the post TER period. This latter result seems odd, suggesting that the revenue situation improved, but this is a result of

changes in the lower end of the distribution (those who earn less than $20,000 from spiny lobster catch in the Tortugas) declined from 72.9% pre TER to 66.6% post TER (Tables 6.23 and 6.24).

At the same time, those who had revenues between $100,000 and $200,000 declined pre to post TER.

Another way to look at dependence is the overall percent of total spiny lobster catch from the Tortugas areas versus other areas where the fishermen who fish for spiny lobster made their catches pre to post TER. In the pre TER period, Tortugas spiny lobster fishermen made 38.8% of their spiny lobster catch from the Tortugas and this increased to 49% in the post TER period (Table 6.19). Most of the shift seems to be from the Key West area to the Tortugas areas. This seems opposite of what one might have expected given the increases in fuel prices, since the Key West areas are closer to port. However, the microeconomic data from Thomas J. Murray & Associates, Inc. (2006; 2007) shows more refined spatial fishing patterns with their Key West Region defined to include parts of the FWRI Tortugas areas. The microeconomic data show a consistent change in pattern of fishing moving closer to port. Thus, while overall spiny lobster catches declined in the Tortugas and other areas of Florida, for fishermen that fish in the Tortugas areas, they have become more dependent on the Tortugas areas pre to post TER.

Table 6.22. Distribution of average pounds of catch for all Tortugas Spiny lobster fishermen: post TER (2002 - 2006).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT 0	316	100.0	100.0
GE 50,000	7	1.9	20.5
GE 25,000	25	7.6	49.3
GE 15,000	42	13.0	64.7
GE 10,000	65	20.3	78.2
GE 5,000	100	31.3	89.9
LT 5,000	216	68.7	10.1
LT 1,000	145	45.9	1.6
LT 500	120	38.0	0.7
LT 100	68	21.5	0.1

1. GT=Greater than; GE=Greater than of Equal to; LT=Less than
2. Average pounds per SPL was equal to 6,760, with min=3.0 and max=77,156.

Table 6.23. Distribution of average revenues for all Tortugas spiny lobster fishermen: pre TER (1997 - 2001).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	332	100.0	100.0
GE $300,000	2	0.6	8.0
GE $200,000	12	3.6	32.7
GE $150,000	21	6.3	47.3
GE $100,000	36	10.8	65.3
GE $50,000	63	19.0	84.6
GE $20,000	90	27.1	93.6
LT $20,000	242	72.9	6.4
LT $10,000	222	66.9	3.8
LT $5,000	197	59.3	1.9
LT $1,000	130	39.2	0.4

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $30,518, with a min=$3.74 and max=$446,640.

The macroeconomic data provide a mixed message and the explanation would seem to be that the declines experienced in the spiny lobster fishery from 2001-2004 were the results of hurricanes and disease, which recent trends in catch show that the spiny lobster fishery is now recovering. Therefore, it appears there is no evidence that spiny lobster fishermen suffered from short run losses due to the TER.

<u>Spiny Lobster Fishery Microeconomic Data:</u> The microeconomic data from Thomas J. Murray & Associates, Inc. (2006) shows that in 1998-1999 there were 36 SPLs, who fished for spiny lobster in the TERSA and were sampled versus 21 SPLs in 2004-2005. This decline in number of SPLs is consistent with the macroeconomic data. The average sampled SPL caught 36,153 lbs of spiny lobster pre TER and 27,000 lbs post TER. This decline in the averages is not consistent with the macroeconomic data averages, but is consistent with the overall decline in aggregate catch pre to post TER. Again, as explained above, the macroeconomic data increase in average catch was a statistical artifact influenced by a movement of a large proportion of fishermen, who caught less than $20,000 worth of spiny lobsters in the Tortugas areas in the pre TER period, who started catching more than $20,000 worth of spiny lobsters from the Tortugas areas post TER. Even though there were declines at the upper end of the distribution consistent with the microeconomic data, the movements up from

the lower distribution resulted in higher mean revenues post versus pre TER.

The microeconomic data also showed that the average sampled fishermen increased the number of traps they fished with from 1,528 traps in the pre TER period to 1,746 traps in the post TER period. Fishers also increased their average trip days of fishing the traps from 105.8 days to 106.4 days, respectively. Since some SPLs own more than one vessel, average days per vessel were also estimated. The average days per vessel increased from 82.8 pre TER to 85.9 post TER. For the sample, overall catch per unit of effort (CPUE) has declined pre to post TER. However, given the overall decline in the number of SPLs, it is not clear in aggregate whether total effort increased or decreased.

Table 6.24. Distribution of average revenues for all Tortugas spiny lobster fishermen: pre TER(2002 - 2006).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	316	100.0	100.0
GE $300,000	2	0.6	7.1
GE $200,000	11	3.5	28.4
GE $150,000	15	4.7	34.9
GE $100,000	31	9.8	54.9
GE $50,000	65	20.6	77.7
GE $20,000	106	33.5	91.0
LT $20,000	210	66.5	9.0
LT $10,000	174	55.1	3.9
LT $5,000	142	44.9	1.7
LT $1,000	90	28.5	0.3

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $32,449, with a min=$19.40 and max=$366,776.

In Thomas J. Murray & Associates, Inc. (2007), an attempt was made to look at CPUE for the aggregate Tortugas areas spiny lobster fishery pre and post TER. Generally, CPUE was lower pre TER to post TER. However, for 2006, CPUE in federal waters was higher than all years in the pre TER period except 1999.

Average trip costs increased significantly from pre TER to post TER, largely because fuel costs more than doubled during that time. With declining CPUE, rising costs per trip and lower prices per pound, spiny lobster fishermen were being squeezed financially from both ends (i.e., receiving less per pound for a lower amount of product and paying higher costs to produce the product).

The microeconomic data also show that fishing has moved closer to the port of Key West. Prior to the TER, 67.1% of reported catch came from the TERSA. After the TER was implemented, 47.0% of reported catch came from the TERSA region. Most of the change in distribution resulted because of increased catch in region two or the Key West region (Thomas J. Murray & Associates, Inc., 2006; 2007). Although region two of the Thomas J. Murray & Associates, Inc., 2006 and 2007 studies are smaller than the FWRI Tortugas areas, it includes some of the FWRI Tortugas areas between Dry Tortugas and Key West. Thus the micro and macroeconomic data on spatial distributions of catch concur and show a movement of fishing closer to the Key West port after the TER was implemented. Alternatively, that movement in fishing effort and catch could be explained by higher fuel prices as well as displacement of fishers by the TER.

With hurricanes, disease, fuel price increase, declines in the price of spiny lobsters, general declines in the number of SPL, and the lobster trap reduction program, it is difficult to assess whether or not the spiny lobster fishery suffered net losses due to displacement from the TER. But with inter-species substitution, spiny lobster fishermen may have been able to mitigate or completely offset any losses by substituting to stone crabs and King Mackerel.

Shrimp Fishery

Leeworthy and Wiley (2000) estimated that only about 1% of the catch by shrimp fishermen that fished in the TERSA would be affected negatively by displacement from the TER. Furthermore, they asserted that shrimp fishers would have no short-term losses if the displaced fishers relocated to other fishing grounds. These conclusions were supported by the macroeconomic data for the Tortugas areas. Total catch of shrimp from all Tortugas areas increased from during the post TER period relative to pre TER catch. Total ex-vessel revenues received from this catch, however, declined significantly from pre to post TER. The decrease in revenues was caused most likely by the collapse in the price of shrimp nationally, which probably resulted from increased

importation of shrimp. Therefore, the shrimp fishery apparently did not suffer any short-term losses due to the TER; and existing data support the original assessment in Leeworthy and Wiley (2000).

Shrimp Fishery Macroeconomic Data: Shrimp catch, primarily pink shrimp, from all Tortugas areas increased from 21.5 million pounds pre TER to almost 26.3 million pounds in the post TER period (Table 6.25). A comparison of the "best" three years in both the pre and post TER periods indicates the post TER catch in the post TER period again exceeds that in the pre TER period, but there the difference is much smaller.

Table 6.25. Catch, landings, ex-vessel value, and prices for Tortugas shrimp: pre versus post TER.

Year	Caught/Landed	Pounds	Nominal[1] Value ($)	Nominal Price ($/lb)	Real Value[2] (2006 $)	Real Price (2006 $/lb.)
1997-2006	**All Tortugas-Catch**	**55,813,771**	**$157,238,858**	**$2.82**	**$179,697,032**	**$3.22**
1997-2006	**Monroe County Landed**	**21,544,889**	**$50,927,248**	**$2.36**		
1997	All Tortugas	5,609,391	$24,200,018	$4.31	$30,398,214	$5.42
1998	All Tortugas	7,833,789	$23,772,591	$3.03	$29,403,328	$3.75
1999	All Tortugas	4,085,844	$14,905,925	$3.65	$18,037,179	$4.41
2000	All Tortugas	3,463,408	$12,825,019	$3.70	$15,014,070	$4.34
2001	All Tortugas	5,267,895	$16,085,815	$3.05	$18,310,546	$3.48
5-year	**Pre- Total**	**26,260,327**	**$91,789,368**	**$3.50**	**$110,231,017**	**$4.20**
2002	All Tortugas	5,438,599	$12,558,524	$2.31	$14,072,752	$2.59
2003	All Tortugas	6,613,754	$13,154,908	$1.99	$14,413,178	$2.18
2004	All Tortugas	6,804,029	$14,268,542	$2.10	$15,227,900	$2.24
2005	All Tortugas	5,343,984	$11,542,466	$2.16	$11,914,189	$2.23
2006	All Tortugas	5,353,078	$13,925,050	$2.60	$13,925,050	$2.60
5-year	**Post - Total**	**29,553,444**	**$65,449,490**	**$2.21**	**$69,466,015**	**$2.35**
	Post - Pre	**3,293,117**	**-$26,339,878**	**-$1.28**	**-$40,765,002**	**-$1.85**
3 years	**Best 3 Years - Pre**	**18,711,075**	**$64,058,424**	**$3.42**	**$78,112,089**	**$4.17**
3 years	**Best 3 Years - Post**	**18,856,382**	**$39,981,974**	**$2.12**	**$43,713,830**	**$2.32**
	Post - Pre (Best 3 Years)	**145,307**	**-$24,076,450**	**-$1.30**	**-$34,398,258**	**-$1.86**

1. Nominal ex-vessel value and prices are not adjusted for inflation.
2. Real ex-vessel value and prices are adjusted for inflation using the Consumer Price Index for All Urban Consumers. Ex-vessel value and prices are converted to 2006 dollars.

The real story from the macroeconomic data is the collapse in shrimp prices from pre TER to post TER. The real price of shrimp received by fishermen declined from an average real price (adjusted for inflation) of $4.20 per pound in the pre TER period to $2.35 per pound in the post TER period. The decline in prices is a national phenomenon. The pre TER average real price for pink shrimp was $4.30 per pound and this declined to $2.36 per pound in the post TER period. Prices for pink shrimp received by fishermen for shrimp from the Tortugas were higher than those received for pink shrimp from the entire Gulf of Mexico or the U.S. However, pink shrimp prices generally plummeted throughout the nation (Table 6.26). The most likely explanation is the rise in imports. Total U.S. commercial fisheries landing for all shrimp were about 179.1 million pounds (heads-off weight) in 1997, while imports were about 810.7 million pounds. By 2006 commercial landings increased slightly to 182.3 million pounds, while imports increased to over 1.7 billion pounds (NMFS, 2007a).

Because of the collapse in prices, total ex-vessel revenues declined significantly from pre to post TER. For the five-year pre TER period shrimp fishermen received over $110 million for their shrimp catch from the Tortugas areas and this declined to about $69.5 million for the five-year period post TER. This is an extremely large loss in revenues and this coupled with the increases in fuel prices have squeezed shrimp fishermen financially from both ends (i.e., receiving less for their total product while paying higher prices for inputs of production).

Table 6.26. Ex-vessel shrimp landings and prices, U.S., Gulf and Tortugas 1997 - 2006.[1]

Year	U.S.		Gulf of Mexico		Tortugas	
	Landings (millions lbs.)	Real Price (2006 $/lb.)	Landings (millions lbs.)	Real Price (2006 $/lb.)	Landings (millions lbs.)	Real Price (2006 $/lb.)
1997	20.65	$3.33	20.05	$3.36	5.57	$5.43
1998	27.65	$2.77	27.11	$2.78	7.81	$3.76
1999	13.50	$3.14	12.70	$3.17	4.02	$4.44
2000	12.75	$3.23	11.69	$3.31	3.42	$4.35
2001	15.98	$2.91	15.21	$2.93	5.16	$3.49
Pre TER Avg.	**18.11**	**$3.08**	**17.35**	**$3.11**	**5.20**	**$4.30**
2002	18.36	$2.08	16.88	$2.10	5.43	$2.59
2003	15.28	$2.02	14.83	$2.01	6.54	$2.18
2004	15.91	$1.93	15.26	$1.94	6.76	$2.23
2005	13.50	$1.97	13.05	$2.00	5.32	$2.23
2006	N/A	N/A	N/A	N/A	5.33	$2.60
Post TER Avg.	**15.76**	**$2.00**	**15.01**	**$2.01**	**5.88**	**$2.36**

NOTE: Real prices are adjusted for inflation using the Consumer Price Index for All Urban Consumers, converted to 2006 dollars. Prices are for pink shrimp.

Dependence on the Tortugas Areas: The number of SPLs that operated in the Tortugas areas declined significantly from 628 pre TER to 436 post TER, about a 30% drop. Shrimping in the Tortugas areas does not follow the 20-80 rule as in other fisheries in the Tortugas. In the pre TER period, 36.5% of the SPLs caught 79.5% of the catch (Table 6.27), while in the post TER period 51.1% of the SPLs caught 86.3% of the catch (Table 6.28). The SPLs caught, on average, 20,612 lbs pre TER and 32,661 lbs post TER. There were 14 SPLs that caught 100,000 or more pounds pre TER and this doubled to 28 SPLs in the post TER period.

Table 6.27. Distribution of average pounds of catch for all Tortugas shrimp fishermen: pre TER(1997 - 2001).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Total Pounds
GT 0	628	100.0	100.0
GE 100,000	14	2.1	12.0
GE 50,000	66	10.4	40.3
GE 20,000	229	36.5	79.5
LT 20,000	399	63.5	20.5
LT 10,000	302	48.1	10.0
LT 5,000	178	28.3	2.9
LT 1,000	59	9.4	0.2

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 20,612 with min=21.0 and max=177,444.

Table 6.28. Distribution of average pounds of catch for all Tortugas shrimp fishermen: post TER (2002 - 2006).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Total Pounds
GT 0	436	100.0	100.0
GE 100,000	28	6.2	24.7
GE 50,000	90	20.4	56.0
GE 20,000	224	51.1	86.3
LT 20,000	212	48.9	13.7
LT 10,000	117	26.8	3.9
LT 5,000	64	14.7	1.2
LT 1,000	8	1.8	0.02

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 32,661 with min=47.0 and max=243,386.

Because of the collapse in shrimp prices discussed above, dependence viewed from a revenue perspective tells a more mixed story. The number of SPLs receiving over $50,000 for their shrimp catch from the Tortugas areas declined from 264 to 222; however, there was a significant move from those who were receiving less than $20,000 to those who received more than $20,000 pre to post TER (Table 6.29 and 6.30). As with the spiny lobster fishery, this change in the distribution of revenues resulted in an increase in the average revenue received by SPLs from $69,537 pre TER to $73,418 post TER. But as noted above, the overall decline in shrimp prices combined with increasing fuel costs probably explains the

consolidation of the shrimp fishery to much fewer SPLs catching more of the shrimp.

Another way to look at fishers' dependence on the Tortugas is to determine temporal changes in the overall percent of total shrimp caught from the Tortugas areas versus other areas where shrimp fishers made their catches. In the pre TER period, Tortugas shrimp fishermen made 34% of their catch from the Tortugas and this increased to almost 41% in the post TER period (Table 6.29 and 6.30). Most of the declines in share of catch were in the aggregate "other Florida" areas, which are north of Tampa in the Gulf of Mexico. A higher proportion of catch was made in the Ft. Myers region pre versus post TER. This trend indirectly suggests that there was a consolidation of the remaining SPLs in the fisheries due to price declines and increasing fuel costs. This consolidation resulted in shrimping activities being based closer to Ft. Myers and Key West, which are close to the Tortugas. Pre to post TER, shrimp fishermen have become more dependent on the Tortugas areas.

From the macroeconomic data, there was no evidence that shrimp fishermen suffered short-term losses from displacement from the TER.

Table 6.29. Distribution of average revenues for all Tortugas shrimp fishermen: pre TER (1997-2001).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	628	100.0	100.0
GE $300,000	11	1.6	8.6
GE $200,000	60	9.4	35.5
GE $100,000	146	23.1	64.5
GE $50,000	264	41.9	84.3
GE $20,000	410	65.1	95.7
LT $20,000	218	34.9	4.3
LT $10,000	126	20.1	1.2
LT $5,000	79	12.5	0.4

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $69,537, with a min=$50.65 and max=$385,905.

Table 6.30. Distribution of average revenues for all Tortugas shrimp fishermen: post TER (2002-2006).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	436	100.0	100.0
GE $300,000	2	0.2	2.5
GE $200,000	29	6.4	22.5
GE $100,000	117	26.6	61.6
GE $50,000	222	50.7	85.2
GE $20,000	332	75.9	96.7
LT $20,000	104	24.1	3.3
LT $10,000	52	11.9	0.8
LT $5,000	27	6.2	0.2

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $73,418, with a min=$157.45 and max=$427,380.

<u>Shrimp Fishery Microeconomic Data:</u> The microeconomic data from Thomas J. Murray & Associates, Inc. (2006) showed that in 1998-1999 there were 19 SPLs, who fished for shrimp in the TERSA and were sampled versus nine SPLs in 2004-2005. This decline in number of SPLs is consistent with the macroeconomic data. The average sampled SPL caught 192,895 lbs of shrimp pre TER and 119,556 lbs post TER. This decline in the averages is not consistent with the macroeconomic data averages. The sampled shrimp fishermen were from the upper end of the distribution of shrimp fishermen(i.e., the ones that catch relatively large amounts of shrimp). As the macroeconomic data show, there was a significant decline in the number of SPLs from the upper distribution, while overall catch increased pre to post TER.

The microeconomic data also show differences on dependence with a shift of SPLs catching 18% of their catch from the TERSA pre TER to 10% of their catch post TER. Again, the Thomas J. Murray & Associates, Inc. (2006; 2007) spatial area definitions for the Tortugas is more limited. The Thomas J. Murray & Associates, Inc. definition of the Gulf of Mexico region includes FWRI Tortugas area, and they show most of the change in distribution of catch coming from the Gulf of Mexico region. This would make the macro and microeconomic data consistent.

The microeconomic data also confirm the rising costs of fuel and the declining prices received by fishermen for their catch, and its effects on shrimp fishermen's decisions. Thomas J. Murray & Associates, Inc. (2006) illustrates this point with the following excerpt from an interview with an area fisherman:

"...a September 2005 interview conducted with a shrimp fisher in Key West, Florida. The respondent stated that he had not taken a trip since the fuel price spike following Hurricane Katrina in late August 2005, and that he did not plan to go out until those prices declined or shrimp ex-vessel values increased. At the time, he argued, he would simply be losing income if he were to take a trip."

Based on both the macro and microeconomic data on the shrimp fishery, there were no short-term losses to the shrimp fishery because of the TER.

Inter-Species Substitution

Leeworthy and Wiley (2000) characterized the Tortugas fishery as a multiple-species fishery, one in which many fishermen depended on multiple species/species groups for their livelihoods. Reef fish and spiny lobster fishermen also depended on King Mackerel and stone crabs. Stone crabs were not caught in the TERSA before the TER was implemented. Thus, there was no displacement of stone crab fishing by the TER. King Mackerel, a pelagic species, was caught in the TERSA but also could be caught outside the TER. In addition, King Mackerel caught inside the TERSA (before the TER) were attracted there most likely by discards from the shrimp fishery. Fisheries for stone crabs and King Mackerel were opportunistic and were not directly affected by the TER. However, these fisheries were impacted indirectly because fishermen displaced by the TER increasingly targeted these two species to compensate for losses in catch of reef fish and spiny lobster that resulted from the displacement. Both the macro and microeconomic data show that spiny lobster fishermen that fish the Tortugas areas have become more dependent on stone crabs and King Mackerel, and revenues from these two species have mitigated losses in revenues that may have resulted from displacement by the TER.

King Mackerel Fishery

King Mackerel Macroeconomic Data: King Mackerel catch by SPLs fishing in the Tortugas areas more than doubled from 1.6 million pounds pre TER to almost 3.7 million pounds post TER (Table 6.31). The number of

Table 6.31. Catch, landings, ex-vessel value, and prices for Tortugas King Mackerel: pre versus post TER.

Year	Caught/Landed	Pounds	Nominal[1] Value ($)	Nominal Price ($/lb)	Real Value[2] (2006 $)	Real Price (2006 $/lb.)
1997-2006	**All Tortugas-Catch**	**5,302,515**	**$4,808,840**	**$0.91**	**$5,303,196**	**$1.00**
1997-2006	**Monroe County Landed**	**5,065,128**	**$4,621,363**	**$0.91**		
1997	All Tortugas	248,725	$205,632	$0.83	$258,299	$1.04
1998	All Tortugas	229,262	$222,708	$0.97	$275,458	$1.20
1999	All Tortugas	361,102	$320,598	$0.89	$387,945	$1.07
2000	All Tortugas	166,866	$130,455	$0.78	$152,722	$0.92
2001	All Tortugas	621,429	$548,443	$0.88	$624,295	$1.00
5-year	**Pre- Total**	**1,627,384**	**$1,427,836**	**$0.88**	**$1,714,706**	**$1.05**
2002	All Tortugas	630,437	$558,912	$0.89	$626,302	$0.99
2003	All Tortugas	788,303	$672,224	$0.85	$736,522	$0.93
2004	All Tortugas	731,085	$673,385	$0.92	$718,661	$0.98
2005	All Tortugas	876,315	$829,656	$0.95	$856,375	$0.98
2006	All Tortugas	648,971	$646,826	$1.00	$646,826	$1.00
5-year	**Post - Total**	**3,675,111**	**$3,381,003**	**$0.92**	**$3,588,489**	**$0.98**
	Post - Pre	**2,047,727**	**$1,953,167**	**$0.04**	**$1,873,783**	**-$0.08**
3 years	**Best 3 Years - Pre**	**1,231,256**	**$1,074,673**	**$0.87**	**$1,270,539**	**$1.03**
3 years	**Best 3 Years - Post**	**2,395,703**	**$2,175,265**	**$0.91**	**$2,311,558**	**$0.96**
	Post - Pre (Best 3 Years)	**1,164,447**	**$1,100,592**	**$0.04**	**$1,041,019**	**-$0.07**

1. Nominal ex-vessel value and prices are not adjusted for inflation.
2. Real ex-vessel value and prices are adjusted for inflation using the Consumer Price Index for All Urban Consumers. Ex-vessel value and prices are converted to 2006 dollars.

SPLs catching King Mackerel in the Tortugas increased from 307 SPLs pre TER to 326 SPLs post TER. This is counter to the general trends of declining SPLs in each fishery throughout the state of Florida and Gulf of Mexico region.

Even though nominal prices increased from $0.88 to $0.92 per pound pre to post TER, real prices (adjusted for inflation to 2006 dollars) declined from $1.05 to $0.98 per pound pre to post TER. Total ex-vessel revenues still more than doubled in real terms from $1.7 million to almost $3.6 million mirroring the overall increase in catch (Table 6.31).

As with many fisheries, the distributions of catch by SPLs is close to the 20-80 rule in both the pre and post TER periods with 19.5% of the SPLs having caught 80% of the catch in the pre TER period and 24.2% of the SPLs having caught 84.3% of the catch in the post TER period. On average, SPLs caught 2,992 lbs pre TER and 6,180 lbs post TER (Tables 6.32 and 6.33).

On average, SPLs fishing for King Mackerel in the Tortugas received more ex-vessel revenues pre to post TER. In the pre TER period the average revenue received was $2,620 and this increased to $5,477 in the post TER period. With maximum revenue in the pre TER period of $64,620, very few if any fishermen depend on King Mackerel from the Tortugas to provide full-time employment. Only two SPLs earned$40,000 or more pre TER. This expanded slightly in the post TER period with five SPLs earning $40,000 or more and the maximum was $140,791 (Tables 6.34 and 6.35).

Table 6.32. Distribution of average pounds of catch for all Tortugas King Mackerel: pre TER (1997 - 2001).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Pounds
GT 0	307	100.0	100.0
GE 50,000	4	1.3	27.4
GE 25,000	11	3.6	49.3
GE 10,000	18	5.9	61.1
GE 5,000	29	9.4	69.1
GE 2,000	60	19.5	80.0
LT 2,000	247	80.5	20.0
LT 1,000	200	65.1	4.9
LT 100	96	31.3	0.4

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 2,992 with min=2.0 and max=83,845.

Table 6.33. Distribution of average pounds of catch for all Tortugas King Mackerel fishermen: post TER (2002 - 2006).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Total Pounds
GT 0	326	100.0	100.0
GE 50,000	4	1.2	21.6
GE 25,000	22	6.7	56.2
GE 10,000	44	13.5	72.5
GE 5,000	79	24.2	84.3
GE 2,000	141	42.9	94.6
LT 2,000	185	57.1	5.4
LT 1,000	138	42.3	1.8
LT 100	65	19.9	0.1

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 6,180 with min=2.0 and max=196,062.

Table 6.34. Distribution of average revenues for all Tortugas King Mackerel: pre TER (1997-2001).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	307	100.0	100.0
GE $40,000	2	0.7	13.9
GE $20,000	13	4.2	47.1
GE $10,000	17	6.5	54.3
GE $5,000	35	11.4	70.3
GE $2,500	60	19.5	82.5
LT $2,500	247	80.5	17.5
LT $1,000	191	62.2	6.3
LT $100	87	28.3	0.4

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $2,620, with a min=$1.50 and max=$64,620.

<u>King Mackerel Microeconomic Data:</u> The microeconomic data from Thomas J. Murray & Associates, Inc. (2006) is not completely consistent with the macroeconomic data. The number of SPLs sampled in the post TER period was less than the pre TER period, with 24 SPLs sampled in the pre TER period and only 13 sampled in the post TER period. The average catches pre to post are consistent with respect to the upwards direction of catch pre to post TER, but the magnitudes of change are not as great as in the macroeconomic data. The average catch was 22,481 lbs pre TER and 23,692 post TER. The distributions of where SPLs catch their King Mack-

erel are in agreement with a higher proportion coming from the TERSA (16.4% pre TER and 29.3% post TER) and from the FWRI Tortugas areas (30.56% pre TER and 64.99% post TER). As with other species/species groups, average trip fuel cost almost doubled pre to post TER.

The overall evidence is that the King Mackerel fishery serves as mitigating and/or offsetting factor to the TER displacement for spiny lobster and reef fish fishermen.

Table 6.35. Distribution of average revenues for all Tortugas King Mackerel fishermen: post TER (2002-2006).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	326	100.0	100.0
GE $40,000	5	1.5	19.7
GE $20,000	23	7.1	46.2
GE $10,000	45	13.8	63.6
GE $5,000	103	31.6	85.3
GE $2,500	141	43.3	92.9
LT $2,500	185	56.7	7.1
LT $1,000	131	40.2	2.1
LT $100	57	17.5	0.1

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $5,477, with a min=$2.50 and max=$140,791.

Stone Crab Fishery

Probably the most important shift in catch was the shift from spiny lobster to stone crabs by spiny lobster fishermen. Previously stone crabs were not caught in the TERSA and so stone crab fishermen were not displaced from the TER. Instead, with spiny lobster stocks down from the impacts of hurricanes and disease, spiny lobster fishermen responded by shifting to stone crabs.

<u>Stone Crab Macroeconomic Data:</u> Stone crabs were not caught west of the Marquesas before the TER was implemented. The Marquesas area was not included in the TERSA, but they are part of the FWRI Tortugas study areas. Stone crab catch increased from 204,622 lbs pre TER to 281,085 lbs post TER (Table 6.36). Besides displacement from the TER and declining spiny lobster stocks, fishermen shifted effort from spiny lobster

Table 6.36. Catch, landings, ex-vessel value, and prices for Tortugas stone crab: pre versus post TER.

Year	Caught/Landed	Pounds	Nominal[1] Value ($)	Nominal Price ($/lb)	Real Value[2] (2006 $)	Real Price (2006 $/lb.)
1997-2006	**All Tortugas-Catch**	**485,707**	**$3,933,389**	**$8.10**	**$4,335,945**	**$8.93**
1997-2006	**Monroe County Landed**	**482,506**	**$3,907,630**	**$8.10**		
1997	All Tortugas	76,000	$202,657	$2.67	$254,562	$3.35
1998	All Tortugas	56,408	$371,640	$6.59	$459,666	$8.15
1999	All Tortugas	34,898	$293,894	$8.42	$355,632	$10.19
2000	All Tortugas	23,274	$202,607	$8.71	$237,189	$10.19
2001	All Tortugas	14,042	$84,100	$5.99	$95,731	$6.82
5-year	**Pre- Total**	**204,622**	**$1,154,898**	**$5.64**	**$1,386,932**	**$6.78**
2002	All Tortugas	10,757	$74,945	$6.97	$83,981	$7.81
2003	All Tortugas	35,603	$322,348	$9.05	$353,181	$9.92
2004	All Tortugas	58,659	$574,277	$9.79	$612,889	$10.45
2005	All Tortugas	72,650	$686,897	$9.45	$709,018	$9.76
2006	All Tortugas	103,416	$1,120,034	$10.83	$1,120,034	$10.83
5-year	**Post - Total**	**281,085**	**$2,778,501**	**$9.88**	**$2,949,013**	**$10.49**
	Post - Pre	**76,463**	**$1,623,603**	**$4.24**	**$1,562,081**	**$3.71**
3 years	**Best 3 Years - Pre**	**167,306**	**$868,191**	**$5.19**	**$1,069,860**	**$6.39**
3 years	**Best 3Years - Post**	**234,725**	**$2,381,208**	**$10.14**	**$2,441,941**	**$10.40**
	Post - Pre (Best 3 Years)	**67,419**	**$1,513,017**	**$4.96**	**$1,372,081**	**$4.01**

1. Nominal ex-vessel value and prices are not adjusted for inflation.
2. Real ex-vessel value and prices are adjusted for inflation using the Consumer Price Index for All Urban Consumers. Ex-vessel value and prices are converted to 2006 dollars.

to stone crabs because of an increase in the real prices (adjusted for inflation) of stone crabs. Real prices for stone crabs increased on average from $6.78 per pound pre TER to $10.49 per pound post TER. Although catch increased a little over 37%, total ex-vessel revenues more than doubled (Table 6.36). The year 2006 was the highest year catch and ex-vessel revenue of stone crabs with ex-vessel revenue topping $1.1 million.

The number of SPLs fishing for stone crabs declined, similar to the trend in the number of SPLs observed in most fisheries throughout Florida and the Gulf of Mexico. There were 121 SPLs fishing for stone crabs in the Tortugas areas pre TER and this declined to 113 SPLs post TER. The stone crab fishery is characterized as being close to the 20-80 rule for catch. Pre TER 25.6% of SPLs caught 80.8% of the stone crabs, while in the post TER period 24.8% of the SPLs caught 76.4% of the catch. Only two SPLs caught 10,000 lbs or more both pre and post TER, but two more SPLs caught 5,000 or more pounds post TER than pre TER. On average, an SPL caught 1,082 lbs pre TER and 1,306 lbs post TER (Tables 6.37 and 6.38).

The distribution of ex-vessel revenues generally mirrors that of catch except one can see the influence of the increases in prices. Pre TER, the maximum ex-vessel revenue received was $65,479, while in the post TER period three SPLs received $100,000 or more with a maximum of $137,928 (Tables 6.39 and 6.40).

Table 6.37. Distribution of average pounds of catch for all Tortugas stone crab fisherman: pre TER (1997 - 2001).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Pounds
GT 0	121	100.0	100.0
GE 10,000	2	1.7	16.4
GE 5,000	5	4.1	29.7
GE 2,500	16	13.2	61.7
GE 1,500	27	22.3	78.1
GE 1,000	31	25.6	80.8
LT 1,000	90	74.4	19.2
LT 500	75	62.0	11.2
LT 100	24	19.8	0.9

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2. Average pounds per SPL was equal to 1,082, with min=2.0 and max=11,088.

Table 6.38. Distribution of average pounds of catch for all Tortugas stone crab fishermen: post TER (2002 - 2006).

Average Pounds/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Pounds
GT 0	113	100.0	100.0
GE 10,000	2	1.8	16.6
GE 5,000	7	6.2	40.7
GE 2,500	16	14.2	61.4
GE 1,500	28	24.8	76.4
GE 1,000	37	32.7	83.9
LT 1,000	76	67.3	16.1
LT 500	58	51.3	6.6
LT 100	26	23.0	0.9

1. GT=Greater than, GE=Greater than or Equal to, LT=Less than.
2.Average pounds per SPL was equal to 1,306, with min=8.0 and max=14,074.

Table 6.39. Distribution of average revenues for all Tortugas stone crab: pre TER(1997-2001).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	121	100.0	100.0
GE $40,000	3	2.5	23.3
GE $20,000	10	8.3	51.3
GE $10,000	18	14.9	67.2
GE $7,500	26	21.7	75.6
GE $5,000	33	27.3	82.7
LT $5,000	88	72.7	17.3
LT $2,500	71	58.7	8.7
LT $1,000	45	37.2	3.2
LT $500	20	16.5	0.6

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $5,853, with a min=$3.75 and max=$65,479.

Stone Crab Microeconomic Data: The microeconomic data and the macroeconomic data are generally consistent. SPLs fishing for stone crabs declined pre to post TER, though the interpretation is a bit different than for other species because stone crabs are not caught in the TERSA. In the microeconomic data the stone crabs caught are those caught by TERSA fishermen who also fish for stone crabs. The microeconomic data reveal that spiny lobster fishermen that fish in the TERSA increased their number of stone crab traps from

- There were mixed results on whether the TER process was fairer than the original FKNMS development process.

Discussion: Tortugas Fisher's Perceptions of the TER Process

The perceptions of the majority of sampled Tortugas fishermen would seem to be inconsistent with several facts. First, the TER process included detailed maps of all the major commercial fisheries catch, which the Sanctuary Advisory Council Working Group (SACWG) used in attempting to minimize impacts on the fishermen, while achieving ecosystem protection goals. This information was further supplemented with information from individual fishermen who attended the SACWG meetings/workshops where fishermen pointed out areas they needed to remain open under various weather conditions.

Second, 12 alternatives were developed by the SACWG in their meetings. Several commercial fishermen served on the SACWG. At the SACWG meeting to select the preferred alternative, the commercial fishermen presented a 13th alternative that was adopted by consensus.

Third, the Governor and Cabinet of Florida and the Gulf of Mexico Fishery Management Council voted unanimously for the SACWG's preferred alternative (the fishermen's alternative).

Thomas J. Murray & Associates, Inc. (2006) offer a possible explanation for this seeming inconsistency. They hypothesize that the commercial fishermen on the SACWG did not represent all commercial fishermen with a particular bias against shrimp fishermen.

However, this again does not seem consistent with the facts. First, the data on catch distributions provided to the SACWG in GIS maps were obtained from 86% of the known fishermen that fished in the TERSA, and these fishermen accounted for over 90% of the catch from the TERSA (Leeworthy and Wiley, 2000). So commercial fishermen were broadly represented in the process. Second, it was determined that shrimp fishermen only depended on 18% of their catch from the TERSA and the preferred alternative only potentially impacted 1% of the shrimp fishermen total catch (Leeworthy and Wiley, 2000). This was the lowest impact across all commercial fisheries. So it would seem that the SACWG commercial fishermen did a good job of representing the shrimp fishermen.

Table 6.42. Tortugas fishermen's perceptions of the TER development process.[1]

Question	N	Mean	Percent Distribution (%)					
			Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Strongly Disagree 5	Don't Know
NOAA considered my fishing grounds in developing boundaries and regulations for the TER and reduced impacts to my fishing grounds.	63	4.22	11.3	4.8	6.5	1.6	71	4.8
The process NOAA used to develop the TER was open and fair to all groups.	63	4.15	11.1	7.9	3.2	4.8	66.7	6.3
Participation didn't matter as the average person had no influence on the final decisions.	63	1.72	69.8	4.8	1.6	0	14.3	9.5
NOAA did not consider local government concerns in the TER designation process.	63	2.01	57.1	3.2	9.5	3.2	14.3	12.7
NOAA did not consider individual citizen concerns in the TER designation process.	63	1.93	65.1	1.6	4.8	3.2	17.4	7.9
The average person has been able to voice their opinion on the usefulness of the TER boundaries and regulations.	63	4.51	7.9	3.2	1.6	3.2	80.9	3.2
The TER development process was fairer than the FKNMS development process.	63	3.19	15.9	3.2	23.8	3.2	22.2	31.7

1. Replication of Table 12 on page 25 of Thomas J. Murray & Associates, Inc. (2006).

1,189 traps pre TER to 1,699 post TER or a 42.9% increase. They also fished those traps more days. Average days of stone crab fishing increased from 37.7 days pre TER to 61.7 days post TER or about a 64% increase. This increase in traps and days fished resulted in average catches increasing from 5,263 lbs to 9,171 lbs. With the increase in real prices, ex-vessel revenues increased as well. As with other fisheries, average trip fuel costs doubled. Curiously, bait costs declined, while crew costs increased, but only slightly. On the whole, stone crabs seemed to have mitigated and/or offset any losses suffered by spiny lobster fishermen due to the hurricanes, diseases and displacement from the TER.

Table 6.40. Distribution of average revenues for all Tortugas stone crab fishermen: post TER (2002-2006).

Average Revenues/SPL[1,2]	Number of SPLs	Percent of SPLs	Percent of Revenues
GT $0	113	100.0	100.0
GE $100,000	3	2.1	23.6
GE $40,000	8	7.1	43.1
GE $20,000	20	17.7	67.3
GE $10,000	38	33.6	84.8
GE $7,500	48	41.5	90.7
GE $5,000	53	46.9	92.6
LT $5,000	60	53.1	7.4
LT $2,500	42	37.2	2.7
LT $1,000	27	23.9	1.0
LT $500	12	10.6	0.2

1. GT=Greater than; GE=Greater than or Equal to; LT=Less than.
2. Average revenue per SPL was equal to $12,941, with a min=$84 and max=$137,928.

ASSESSMENT OF FISHERS' KNOWLEDGE, ATTITUDES, AND PERCEPTIONS OF TORTUGAS ECOLOGICAL RESERVES AND FLORIDA KEYS NATIONAL MARINE SANCTUARY

This section presents assessments of the knowledge, attitudes and perceptions of Tortugas fishermen about marine protected areas and no-take reserves. The information was summarized from Thomas J. Murray & Associates, Inc. (2006) and Shivlani et al (2008) on a 10-year replication of a study on knowledge, attitudes and perceptions of FKNMS management strategies and regulations, with particular focus on no-take zones. For details on survey methodology and discussion please see Thomas J. Murray & Associates (2006).

Fishers Knowledge

There was a fairly high participation rate among sampled Tortugas fishermen in the TER development process with attendance at meetings and workshops being the number one source of information (49.2%). One hundred percent of the sampled Tortugas fishermen had knowledge of the TER boundaries and regulations with the number one source of information being literature provided by the various management agencies (60.3%). Results are summarized in Table 6.41.

Table 6.41. Tortugas fishermen's knowledge and sources of information for TER.[1]

Item	Percent
Participated in the TER process	57.1
Sources of Information	
1. TER meeting and workshops	49.2
2. Reading TER newsletters	36.5
3. Media	34.9
Knowledge of TER boundaries and regulations	100.0
Sources of Information	
1. Literature provided by FKNMS, Gulf of Mexico Fishery Management Council and other agencies	60.3
2. Other fishers and/or fish houses	36.5
3. Media	12.7

1. From Shivlani et al (2008).

Fisher Attitudes and Perceptions of the TER Process

- The majority (67%) of sampled Tortugas fishermen did not consider the process in developing the TER as fair nor did they think that individual fishermen/citizens or local government concerns were considered in the process (Table 6.42).
- The majority (71%) of sampled fishermen did not think their fishing grounds and the impacts of the TER on them were considered in establishing the TER boundaries and regulations (Table 6.42).

Thomas J. Murray & Associates, Inc. (2006) did also offer an alternative explanation for this inconsistency in perceptions and facts. Simply, fishermen did not like the outcome. But as was noted above, it was the fishermen's alternative that was adopted by consensus by the SACWG, the governor and Cabinet of Florida, and the Gulf of Mexico Fishery Management Council. Further, a key element of the adopted alternative was TER South, which totally protected Riley's Hump. Riley's Hump was widely recognized by fishermen as being an important spawning site for some reef fish and fishermen wanted this area protected from all fishing, including recreational fishing, which was done.

One explanation for this inconsistency between perceptions and facts would seem to be that the majority of fishermen didn't want any no-take areas and what they proposed, and got, was the best deal they thought they could get. Below in the discussions about the attitudes and perceptions of outcomes, another explanation is offered that focuses on the institutional situation in fishery management.

Attitudes and Perceptions of Outcomes and Support of the TER and FKNMS

Sampled Tortugas fishermen were also asked eight questions on various outcomes of the TER as well as support for the TER and the FKNMS (Table. 6.43).

- The majority of sampled Tortugas fishermen did not think that they benefited from the TER or that the TER was a benefit to the Florida Keys economy.

- In contrast, a near majority to a majority did think that the TER protections improved natural resource conditions within the protected areas and that nonconsumptive users, who were not displaced from Tortugas North, were the primary beneficiaries of the TER.
- The majority of sampled Tortugas fishermen did not support establishment of the TER (60.3 to 61.9%), nor did a majority support establishment of the FKNMS (57.4%).

- However, Thomas J. Murray & Associates, Inc. (2006) point out that the lack of support has significantly improved since the 1995-1996 assessment (Milon et al., 1997) and the one they had done in the baseline TERSA study in 1998-1999.

Table 6.43. Tortugas fishermen's attitudes and perceptions of TER outcomes and support of TER and FKNMS.[1]

Question	N	Mean	Percent Distribution (%)					
			Strongly Agree 1	Agree 2	Neutral 3	Disagree 4	Strongly Disagree 5	Don't Know
The TER has replenished stocks in the region.	63	4.02	14.3	3.2	4.8	4.8	55.6	17.5
The TER has improved stocks within the reserve boundaries.	63	2.71	34.9	7.9	1.6	0.0	28.6	27.0
The TER has conserved and protected corals, fish, and other marine life within the reserve boundaries.	63	2.2	44.4	11.1	4.8	1.6	17.5	20.6
My catch within the TER region has increased since the implementation of the TER.	61	4.47	3.3	0.0	18.0	1.6	73.8	3.3
The TER is the most effective way to protect and restore coral reefs in the region.	61	3.33	27.9	6.6	8.2	0.0	45.9	11.5
The long-term effects of the TER on the economy of the Florida Keys (region) have been positive.	63	4.04	20.6	1.6	0.0	0.0	68.3	9.5
I favor establishment of the TER.	63	3.81	19.0	3.2	15.9	0.0	60.3	1.6
- TER North	63	3.87	15.8	6.3	14.3	0.0	61.9	1.6
- TER South	63	3.77	23.8	1.6	7.9	4.8	60.3	1.6
I favor establishment of the FKNMS.	61	3.76	16.4	11.5	8.2	4.9	57.4	1.6

1. From Thomas J. Murray & Associates, Inc. (2006) pages 26-27.

- From the 1995-1996 study, 70% and 78.1% of the sampled respondents did not support the establishment of no-take zones in the Lower Keys and Dry Tortugas and the FKNMS, respectively.

- From the 1998-1999 study, 77.9% were against a reserve being established in the Dry Tortugas region and 70.5% were against establishment of the FKNMS.

Discussion - Tortugas Fishermen's Attitudes and Perceptions of TER Outcomes and Support for the TER and FKNMS

Perceptions on increased catch from the sampled Tortugas fishermen are not consistent with the pre and post TER quantitative information presented in this assessment. Catch increased pre to post TER for reef fish, shrimp, King Mackerel and stone crabs. Only small declines for spiny lobster were detected, but the declines started before the TER closure and persisted through 2003, but since 2004 have been on an upward trend, with 2006 being the highest year of catch for the 1997-2006 period. Part of the explanation here for this inconsistency between perceptions and facts is the timing of the survey. The survey was largely about what had taken place up through 2003 and there was not much of a change in reef fish catch for years 2000-2003 (Table 6.14), while spiny lobster catch declined from 2001 to 2003. In addition, biologists did not expect there would be replenishment effects in the short-run so one would not expect that fishermen to have experienced increased catches. As shown, the increases in reef fish were the result of fishing new fishing grounds previously not exploited, but this did not happen until 2004.

Measures taken on attitude and perceptions in both the 1995-1996 and 1998-1999 studies were done under conditions of great uncertainty. Fishermen were being asked to give up fishing grounds with high uncertainty of whether they would benefit from such actions. The existing fishery management institutional arrangement is still characterized as an open access, common property fishery despite the lobster trap reduction program and other regulations that partially limit effort. Under such an institutional arrangement, fishermen cannot be assured they will personally benefit from any investment in improving the fisheries, and therefore a majority of fishermen might not support (i.e., sacrifice by giving up fishing grounds) any regulation or management strategy that purports to yield future returns if an investment is made. However, Johnson and Libecap (1982) demonstrated that some fishermen might support such investments, even under open access, common property conditions, because they have superior knowledge and skills, and can thus capture the benefits of such investments. This explains why anywhere from 21-36% of fishermen support both the TER and FKNMS.

As to the improvement in support for the TER and FKNMS, as noted the baseline measures were taken in 1995-1996 and 1998-1999. The FKNMS management plan and regulations, including the original 22 sanctuary preservation areas and the first ecological reserve (Sambos) did not go into effect until July 1, 1997, and the TER did not go into effect until 2001. By the 2004-2005 survey, the fishermen had time to experience the effects of the FKNMS management plan and regulations and many of the fears generated by uncertainty were reduced. As this chapter shows, short-term economic losses due to the TER did not occur, and as shown in Leeworthy (2001), short-term losses did not occur for Sambos fishermen.

SUMMARY AND CONCLUSIONS

There have been many reports and journal articles addressing the social and economic (socioeconomic) impacts of marine protected areas (MPAs) and the special class of MPAs, marine reserves (MRs) or no-take areas (Berman et al., 2008; Holland, 2000; Mascia, 2003; Sanchirico et al., 2007). However, all of these efforts have not addressed the question of what actually happens. Past efforts have focused on expected possible outcomes based on either theory and/or have modeled behavior based on reasonable assumptions. To actually determine what happens, in most cases, requires a pre-post implementation assessment requiring monitoring data.[D]

D. Most cases involve marginal or small changes in the total amount of activity affected. In cases where large changes occur (New England Groundfish Closure) economic and social impacts are clear and real. In the New England Groundfish Closure, it was projected that even after stock recovery, 50% of fishermen would not get their jobs back. The federal government moved to set up compensation and assistance programs to help fishermen transition to new livelihoods.

Here the results of the first pre-post integrated assessment of the socioeconomic impacts of a MR, the TER in the FKNMS, are reported (results are summarized in Table 6.44 at the end of this section). At the time of its creation (July 2001), it was the largest MR in the U.S. (151 nm^2). Five-year pre implementation and five-year post implementation periods were used for the assessment with five years serving as the period for determining short-run impacts.

Most of the literature assumes that for those who are displaced from MRs, there will be short-run losses, which economists refer to as opportunity costs. The findings stated here run counter to all of the theoretical papers and modeling efforts that assume there will be short-run opportunity costs associated with MRs. The data indicate in the short-run neither those who participate in the commercial fisheries, nor the recreational fisheries experienced any financial losses due to implementation of the TER (Table 6.7). And, given that there were no financial losses, it can be concluded that there were no wider social costs. There were no major disruptions that could lead to family and community problems as indicated by unemployment, general crime rates, domestic violence and substance abuse.

In the recreational fisheries, effort did shift to other areas away from the larger Tortugas area closer to home ports, but this was due to rising fuel costs and new grouper regulations that made the trip to the Tortugas area a less preferred choice. It was simply not worth the cost to go all the way out to the Tortugas area for a couple of grouper. None of the charter fishing guides thought that the TER affected their business.

For the commercial fisheries, there was also a shift in effort away from the Tortugas area towards fishing

Table 6.44. Summary of major findings from assessment of socioeconomic impacts from no-take reserves in Tortugas.

	Initial Assessment Projections[1]		
	Step 1	**Step 2**	**Current Assessment**
Commercial fisheries[2]	--	--	--
Reef Fish	116,642 (20.3%)	Projected losses highly likely to occur since reef fish are considered overfished throughout the region. Thus, fishermen not expected to be able to relocate and make up lost catch.	No losses due to closed areas. Reef fish catch increased from pre to post establishment of the TER. This was opposite of expectations. Reason was that displaced fishermen found new areas previously not fished and these areas were not sampled by biologist and were not included in stock assessments.
Spiny Lobster	108,639 (11.6%)	Projected losses not likely to occur because lobster trap reduction program will allow for relocating traps and fishermen are knowledgeable and fish other locations throughout the Florida Keys.	No losses due to closed areas. Spiny lobster declined from 2001 through 2003 due to hurricanes and disease. Spiny lobster catch recovered 2004 through 2006 reaching record levels. Short-run losses in 2001-2003 offset by fishing for stone crabs and king mackerel.
Shrimp	58,374 (8.2%)	Projected losses not likely to occur. Shrimp fishermen catch only 10% of their total catch from the Tortugas Area and displacement will impact only 8% of catch from the Tortugas Area and only 1% of total catch from all areas. Should be able to relocate and make up catch from other areas.	No losses due to closed areas. Shrimp catch increased from pre to post establishment of TER. However, prices declined due to large increases in imported shrimp and total revenues received by fishermen declined.
King Mackerel	13,489 (14.0%)	Projected losses not likely to occur. King mackerel is a pelagic species and are thus highly mobile and there are no special features in closed areas. Expect fishermen can relocate to other areas and make up lost catch from closed area.	No losses due to closed areas. Catch increased pre to post establishment of the TER.

1. Initial projections of losses from Leeworthy and Wiley (2000). The approach used a two-step analysis. Step 1 was quantitative and simply assumes all commercial catch or recreational activity would be lost from area closed. This represents “maximum potential loss”. Step 2 looks at all mitigating and off-setting factors and provides qualitative assessments of how likely step 1 losses are to occur.
2. Pounds of catch from closed area.
3. Person-days of displaced activity.

grounds closer to home ports due to fuel price increases. But, the actual changes in catch and revenues received by fishermen from the Tortugas area pre to post varied considerably by fishery.

The most interesting finding was that for the reef fish fishery. During the design and evaluation phase of the TER (initial assessment), the biophysical scientists had concluded that reef fish in the Tortugas area, as well as in the rest of the Florida Keys, were overfished. This assessment led the socioeconomic team to conclude that there would be losses to the reef fishermen since they would not be able to relocate to other fishing grounds and make up for lost catch from the TER. However, reef fish catch from the Tortugas area actually increased pre to post TER and is on an increasing trend. The reason for this disparity was that displaced fishermen found new areas previously unfished and these areas were not sampled by biophysical scientists, and were therefore not in their stock assessment. Based on the data, the current upward trend in reef fish catch from the Tortugas area reflects the expansionary phase of a new fishery. The projection of losses in the initial assessment was based on the assumption of perfect knowledge by both the scientists and the fishermen. For the fishermen, it is assumed they knew all the available fishing grounds and the fishing choices made in the pre TER period were the profit maximizing choices. In reality, fishermen did not have perfect knowledge and displacement from the TER led them to discover new fishing grounds (necessity is the mother of invention).[E]

For the shrimp fishery, the initial assessment concluded that losses would not likely occur because of the low dependence of shrimping operations on the TER for their total catch. In the post TER period, total catch from the Tortugas area actually increased, but revenues for that catch significantly declined due to large reductions in shrimp prices resulting from large increases in imported shrimp.

For the King Mackerel fishery, the initial assessment projected no losses because King Mackerel is a pelagic species and therefore is highly mobile. In addition, there were no special features in the TER which attracted or aggregated them. Catch lost from displacement from the TER could be made up by relocating to fishing grounds outside the TER. In the post TER period, King Mackerel catch increased as did revenues received from the catch.

The spiny lobster fishery highlighted why an integrated assessment is important and also illustrated the importance of accounting for interspecies substitution. In the pre TER period, spiny lobster catch was in decline in the Tortugas area. The decline continued through the first two years of the post TER period, then started to increase with a record year in the 5th year of the post TER period. The biophysical scientists were able to explain the decline in the spiny lobster catch as being the result of hurricanes and a larval disease. The upward trend in catch at the end of the post TER period indicates the fishery has recovered from these effects and is now meeting or exceeding catches experienced in the beginning of the pre TER period. So again, the data indicate there were no losses attributable to the TER.

Evaluation at the fishing operation level across all fishing catch and revenues revealed that spiny lobstermen also participate in multiple fisheries and were able to increase their catch of King Mackerel and stone crabs to offset any losses from the reductions in spiny lobster catch (interspecies substitution) during the years when spiny lobster were in decline.

E. A caveat is that if fishermen are taking bigger risks in fishing new fishing grounds they did not fish in the past because oceanographic and weather conditions rendered them more dangerous to fish. Regulations often have unintended consequences (Pendleton et al., 2001) .

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Chapter 7: Social and Economic Effects of Tortugas Ecological Reserve to Recreation Businesses that Utilize the Dry Tortugas Area

David K. Loomis[1], Christopher Hawkins[1], Douglas Lipton[2] and Robert B. Ditton[3]

INTRODUCTION AND BACKGROUND

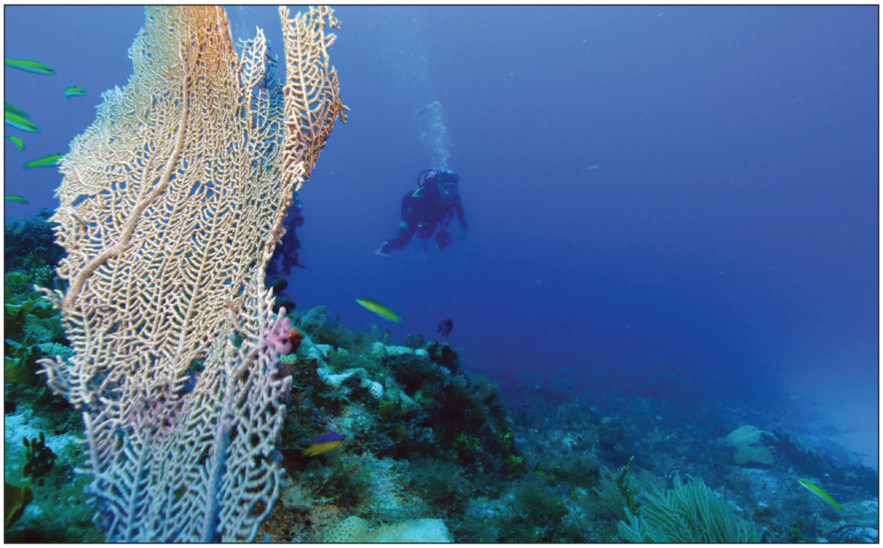

Figure 7.1. Purple sea fan and diver. Photo: NCCOS Center for Coastal Fisheries and Habitat Research (CCFHR).

Recreational activities represent a prominent use of natural resources in the Tortugas region (Figure 7.1). To complement the analysis of commercial fisheries data to determine short-term socioeconomic impacts, data on recreational activities were also analyzed to evaluate short-term effects of the Tortugas Ecological Reserve (TER) on recreational businesses operating in the Tortugas region. A study published in 2000 entitled *Socioeconomic Impact Analysis of Alternatives* (SIA; Leeworthy and Wiley, 2000) outlined potential economic and social impacts of the TER on recreational businesses based on five proposed alternative scenarios for TER implementation. At the time, few private boaters made the 140 mile roundtrip from Key West to the Tortugas area. Therefore, the impact analysis primarily collected qualitative data on the for-hire recreation industry (dive boats and fishing charters), although quantitative approaches were also used to understand private recreational use of the TER study area.

The purpose of this study is to provide follow-up data with regard to the for-hire recreation sample to understand any social and economic impacts to these groups as a result of the creation of the TER. The current trends in private recreational fishing in the Tortugas region are discussed here. The first half of this chapter describes the methods and results of the 2000 SIA to provide context and to serve as a baseline for data on recreational activities collected during 2006. The second half presents data obtained through telephone and in-person surveys and describes social and economic impacts of the TER to recreational businesses that were operating in the Tortugas region during 2006.

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RESULTS OF THE 2000 SOCIOECONOMIC IMPACT ANALYSIS

The 2000 SIA identified a list of potential operators through three primary means: (1) a Dry Tortugas National Park (DRTO) listing of permitted for-hire operators; (2) “snowballing,” in which these operators were asked to identify additional relevant individuals; and (3) commercial (non-charter/non-recreational) fishermen, who were asked about boats they saw consistently in the study area (very few). From this research, a list of 23 potentially relevant operations was developed. Of these 23, seven could not be contacted, despite repeated attempts. Thus, the final list was set at 16 boats (12 businesses) and was considered a census. Individuals were then interviewed by telephone and in person (Table 7.1).

Table 7.1. Final list of operators in the 2000 study.

Charter boats	Party boats
Playmate	*Yankee Capts*
Katmandu	
Andy Griffiths Charters	
Ultimate Getaway	
Tiburon	
Lisa B	
Triple Time	
Captain Marvel	
Miss Rene	
Whisker Charters	
Dennis Smith (boat name not known)	

Data Collection

The data collected by Leeworthy and Wiley (2000) included the following: person-days of activity, revenue, cost and profit by activity. These variables were quantified by month, and across four activities (non-consumptive diving, diving for lobster, spear fishing, and hook and line fishing). These activities were identified as being all of the recreational activities occurring in the study area. In addition, participation within these activities was found to be limited because of the time and expense one must invest in making the lengthy trip to the Tortugas area, as well as the lack of lodging in the small islands that comprise the Dry Tortugas. While many people do make the trip to the DRTO, (approximately 72,000 visitors in 1998) few of these people were found to leave the park boundaries to undertake side trips to the study area.

The 2000 study focused on potential non-market and market economic losses that could result from displacement of consumptive recreational activities. The market economic values were identified as revenues from the party and charter boat operations that catered to the consumptive segment of the study area users. These revenues were then analyzed further in terms of the impact of total output/sales, income, and employment on the Monroe County economy. These impacts included multiplier effects. Non-market values were assessed in terms of consumer’s surplus and producer’s surplus. Activities in these categories included spear fishing, and fishing and diving for lobsters (Figure 7.2).

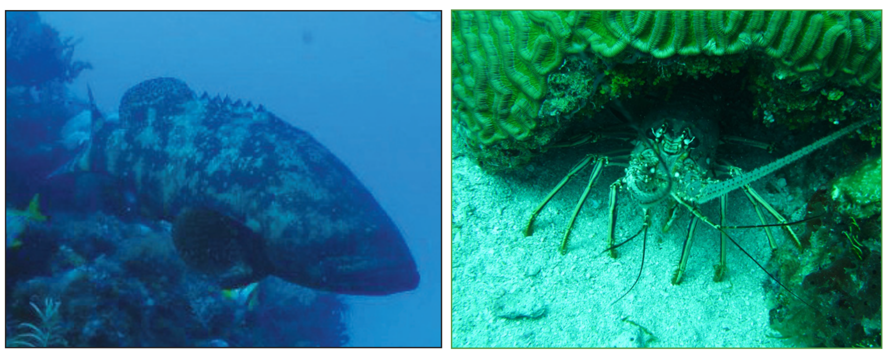

*Figure 7.2. Goliath Grouper (*Epinephelus itajara*; left) and Caribbean spiny lobster (*Panulirus argus*; right) in the Dry Tortugas National Park (DRTO). Photos: NCCOS CCFHR.*

The SIA used the data capture technique of snowball sampling by asking Tortugas charter operators if they had seen or were aware of other similar businesses operating in the study area and if they had seen private fishing and diving boats outside of the DRTO boundaries. All answered that they had seen only the other boats identified in the sample and had not seen any private recreational boats in the study area. Finally, the SIA included contacting all the known fishing clubs in South Florida to ascertain whether their members regularly went to the study area (not including the DRTO). The information gathered from the clubs confirmed that only on rare occasions do their members make this trip.

Results of Leeworthy and Wiley (2000)

Survey results showed that these firms supplied 21,027 person-days of recreation, mostly within the FKNMS boundaries. The activities were: fishing (78%), spear fishing (9%), diving for lobsters (8%) and non-consumptive diving (5%). The net benefit to recreators (consumer surplus) as calculated by applying a person-day value was $1,665,643. Profits for these firms, used as a relative indicator of producer surplus, amounted to just over $400,000.

Potential impacts of reserve designation were reported across five alternatives proposed for the TER. Alternative III, the current reserve boundary, was identified by the Tortugas Working Group as the preferred option. With regard to non-market values, NOAA reported that under Alternative III approximately 26% of the total person days of diving for lobster, approximately 26% of the total person days of spear fishing and just over 3% of the total person days of fishing would be displaced. In total, a little more than 7% of person days across all three activities would be negatively impacted by reserve designation. The monetary estimate for this impact was that $125,163 of the consumer surplus could be displaced by the reserve and $55,786 of the operator profits could be lost.

Alternative III analysis suggested that nine of 12 charter operations would potentially incur market value impacts. Economic losses in the form of direct business revenue were projected to be 26.6% for diving for lobster, 20% for spear fishing and 6.3% for fishing. Across all three activities, 11.7% of revenue could be potentially impacted. The report concluded that these potential losses, though noticeable to the individual charter operations, would likely not be felt by the greater Monroe County economy, as they represented only a fraction of 1% of the revenue generated by recreating visitors to the Florida Keys.

The figures presented in the SIA are termed “maximum total potential losses.” It is made clear that these estimates are only valid if the operators were to completely abandon those components of their business that occurred inside of what was proposed to be and is now the TER. However, if these operators were to shift their activities geographically to accommodate the new reserve boundaries, it was reported as unlikely that the maximum losses would be realized. This shift is known as substitution. Substitution is one response to the displacement that occurs after an area is closed to previously-allowed activities. Substitution, together with the potential of long term benefits from the hoped for fishery replenishment effects of creating the reserve, are defined by Leeworthy and Wiley (2000) as mitigating factors.

POST TORTUGAS ECOLOGICAL RESERVE SOCIAL AND ECONOMIC IMPACTS TO RECREATIONAL BUSINESSES – 2006

Background

In 2005, the University of Massachusetts Amherst's Human Dimensions of Marine and Coastal Ecosystems Program was contracted to examine the social and economic impacts, if any, on the 12 businesses reported in the 2000 SIA, and to understand what, if any, wider effects reserve designation has had on the Tortugas for-hire fishing and dive industry. Specific themes of interest in the present research are: (1) understanding the economic impacts of reserve designation; (2) determining relevant social and economic factors that have/are contributing to the use or non-use of the Tortugas for for-hire fishing and diving; (3) obtaining a picture of private recreational fishing in the Tortugas area; (4) presenting attitudes towards the reserve and of the current quality of fishing and diving near there; (5) determining if there has been a switch to non-consumptive uses as a result of Tortugas implementation; and (6) whether operators are using the TER as a selling point in their advertising.

One goal of this research was to demonstrate a long-term commitment to understand those stakeholders potentially affected by the TER designation. A second goal was to continue to build on existing knowledge regarding the social and economic effects of reserving fishing areas in order to make the best possible predictions in similar cases in the future. Presented here is a shortened version of the analysis of the recreation industry. For the full report see Loomis et al. (2007).

The current project used an interdisciplinary social and biophysical science approach. In December 2005, a meeting was held at the Southeast Fisheries Science Center in Miami, which provided an opportunity for relevant individuals to meet and discuss the history and goals of this effort, especially in terms of the integrated assessment approach utilized by NOAA. Following this meeting, an initial assessment of the Tortugas for-hire fishing and diving universe (locations of boats, numbers of operators, etc.) was conducted in Key West.

Methods

To initiate the data collection, 61 charter vessels in the Key West area were contacted by telephone and in person from a wider list developed by an extensive search of various sites (e.g., the phone directory, Internet, Florida Keys Tourist Development Council). Time and logistical constraints did not allow the team to contact all charter operators on this list, and in many cases operators were clearly not appropriate, due to the nature of their business or boat size. The sample of 61 was based primarily on boat size and range. Of the 12 businesses identified by Leeworthy and Wiley (2000), researchers were able to find seven, and these were included in this sample. Additionally, methods ensured that those who were identified as new Tortugas area operators were captured in the sample. With regard to new operators, the only new individuals identified were captains who have been hired to work for an existing Tortugas charter company. While they represent new additions as captains, the business they work for, Andy Griffiths Charters, is not new to the Tortugas area. This study also found four individuals not listed in the 2000 survey, but that identified themselves as having previously been engaged in for-hire Tortugas trips. Finally, the president of the Keys Area Dive Operators Association indicated that, to his knowledge, no additional dive business had begun regular Tortugas operations.

The rationale for starting with a greater number of operators was to ensure that any boats that may have entered the Tortugas for-hire fishery since 2000 would be captured and it was hoped that contacting a larger group of people would assist with this goal. It was found in speaking with these captains that many of the same names were mentioned repeatedly. The final list of relevant businesses was narrowed to 21 (fishing=19, diving=2). This was considered a census (Table 7.2).

Initial telephone and personal contacts with operators indicated that a simple re-creation of the 2000 SIA was going to be of little value in understanding how reserve designation has impacted for-hire fishing and diving operators utilizing the Tortugas area. This is primarily because the data generated would offer little in understanding the complex issues involved in the Tortugas for-hire recreation industry. Events since the creation of the TER have altered the operational climate. Factors such as fuel and insurance costs, as well as changes in fishing regulations and drops in tourism are important and relevant factors in how people might or might not

use the TER. Changes in activity level in and around the TER may have much more to do with these factors than with the creation of the TER itself. Thus, it is not possible to make a simple and straight-forward comparison of the before and after TER for-hire activity. To do so would likely result in erroneous conclusions. In other words, a report illustrating the current economic status of those operators who still or no longer make regular trips to the Tortugas area to fish and dive would ignore various intervening variables inherent in determining the economic feasibility of Tortugas operations. Therefore, this research concentrated on a particular set of variables (discussed below), in order to present a fuller picture of the current attitudes and issues of Tortugas operators.

Table 7.2. Final list of operators in re-study.

Charter Boats	Party Boats
Andy Griffiths Charters	Florida Fish Finder
Andy Too	Yankee Capts
Mean Green	
Ultimate Getaway	
Leathal Weapon	
Tiburon	
Ultra Grand Slam	
Tortuga Hooker	
Playmate	
Triple Time	
Captain Marvel	
Conch Too†	
Cha-Cha†	
Miss Kasey†	
John Weinhofer (boat name not known)†	
Miss Rene*	
Whister Charters*	
Lisa B*	
Dennis Smith (boat name not known)*	

†Indicates individuals not on the 2000 Socioeconomic Impact Analysis of Alternatives (SIA) list that claim to have gone to the Tortugas area prior to reserve designation but who no longer do.

* Indicates charger operators on the 2000 SIA that we could not find in 2006.

In late February 2006, interviews were conducted with charter owners, captains, and mates from the above list of 21 relevant operator businesses. During our initial conversations with Tortugas and other operators, it became apparent that there were a variety of factors that were relevant to whether fishing and diving businesses made the 140-mile roundtrip to the Dry Tortugas area, and that these factors were independent of the establishment of the reserve. This finding prompted a change in our approach to data collection and analysis.

Given that many operators stated that either (a) other (non reserve) factors were at work; or (b) sustainable fishing and diving locations were readily available due to the sheer size of the Tortugas area, a survey instrument was developed to examine, among other things the range of possible reasons for not making Tortugas area fishing and diving trips, as well to collect information about previous and current Tortugas activity, and attitudes about the quality of fish and diving pre and post reserve implementation. Two survey instruments were developed and administered onsite or mailed to 23 individuals associated with these 21 for-hire businesses to address the main questions of who is using the area, how often, why, and their views of the quality of fishing and diving in the Tortugas, as well as their views on private fishing, non consumptive use and advertising (see Appendix III).

While in Key West, and in subsequent phone calls and mailings from the university, 23 surveys were administered. Twenty of these were completed by individuals associated with Tortugas fishing charters and two were completed by individuals associated with dive charter operators. Of these individuals, 10 were operators, five were owners, four were owner/operators and one was a mate. All but two listed their vessels as charter boats, and one considered himself both a charter and a party boat because of capacity. It should be noted that the dive charters are different from the more typical head boats found operating on the Florida Keys reefs. The two dive charters in this sample run different, more intimate boats.

In June 2007 a third trip to Key West was made to interview knowledgeable respondents regarding three questions pertinent to recreational use in the Tortugas area. The first question concerned the numbers of personal recreational boats fishing between Rebecca Shoal and the Tortugas area. This question is related to the num-

ber of fish being removed (potentially) from the ecosystem, and the impact of that removal to the effectiveness of the reserve. The second question concerned whether operators previously going to the area that is now the TER have switched from consumptive activities to non-consumptive activities. The third question was whether or not Tortugas-based operations are using the reserve as a component in their advertising. For example, dive operators might conceivably point out that a large no-take area will provide for larger fish and better reef conditions, while charter anglers might point to more and larger fish "spilling over" from the closed areas. Findings related to these three questions can be found in the Results section under "Private Fishing, Non Consumptive Use and Advertising."

Results

Intervening Variables

As stated previously, the survey instrument was developed to understand a more comprehensive, and seemingly more important, range of factors that have affected or may affect Tortugas activity. These factors are termed "intervening variables," because they interfere (or can interfere) with the ability to attribute longer and shorter term economic changes in the Tortugas-based for-hire recreational diving and fishing industry. As such, data about these variables allows for a better picture of the social and economic factors that may be related to the for-hire activity in and around the TER. Discussions with operators of what socio-economic variables might be important resulted in several questions regarding fuel prices, number of clients desiring to go fishing in the Tortugas, and availability of fish. Two additional themes were encountered during data collection: the effects of fishing regulations and the interplay between sanctuary and park rules and administration. In addition, Florida tourism trends are addressed.

Fuel Prices

Fuel is a constant concern for charter boat operators who routinely fish or dive long distances from their home port. Additionally, as fuel prices climb, so do the prices of associated products, such as lube oil. Therefore, a factor that has apparently affected trips to the Dry Tortugas area is that fuel prices have risen 133% in South Florida since 1999 (U.S. Department of Labor). Thirteen individuals answered the fuel component of question seven, which asked respondents to rank how important each of nine items was as a current reason not to make trips to the Tortugas. Of these, five ranked the issue as "extremely important," six ranked it as "very important" and two ranked it as "somewhat important."

Clients

A shortage of customers willing to pay for and expend the time on a Tortugas trip will certainly have a negative impact on business. There are two trends to consider here: the trend in overall tourism in Florida and customer interest in Tortugas trips. With regard to general trends, data that were generated in the original SIA were related in part to booming tourism. Person trips to Florida increased from 50 million annually in 1998 to approximately 74 million annually in 2000, a bump of almost 150% in just two years. However, tourism visits to Florida fell approximately four million person trips in 2001, and have been erratic since (Visit Florida Research, 2006; http://media.visitflorida.org/research.php). There are several probable reasons for this decline, including the 2001 terrorist attacks on the United States, increased hurricane activity, red tides, transportation issues and changing tourist behavior patterns (Visit Florida Research, 2006). However, for Tortugas operators, this does not appear to be an issue. Twelve individuals answered the client component of question seven. Of these, only three ranked too few clients as a current reason for not making trips. A majority of the remainder ranked this issue as currently "not at all important." Three ranked it as "somewhat important" and one person ranked it as "slightly important."

Availability of Fish in the Tortugas

If a fishery experiences drastic stock declines, then the potential exists for recreational and commercial operations to exit, because there will not be enough fish to sustain the business. However, this did not appear to be a concern among the Tortugas operators. In fact, most spoken with indicated the fishing was excellent in the Tortugas area. Thirteen individuals answered the fish component of question seven. Of these, 10 ranked too few fish as "not at all important" for not making trips. One ranked it as "somewhat important" and two people ranked it as "slightly important." Regardless of the results of biological studies of fish stocks in the Tortugas area, the perception clearly exists among charter operators that the region has experienced no significant losses in fish biomass.

Fishing Regulations

Many operators cited recent and historical fisheries management decisions as harmful to their business. Specifically mentioned were the Red Grouper (*Epinephelus morio*) limit of one fish per person (and per vessel) on the Atlantic side, the Black Grouper (*Mycteroperca bonaci*) bag limit of two fish per person, and the total bag limit of five grouper (Florida Fish and Wildlife Conservation Commission, 2007). Several operators mentioned that the small grouper limit was worrisome.

Grouper is an important fish to Tortugas-based fishing operations (Figure 7.3). All of those who answered question five and question 12 listed grouper as desired species to catch. In fact, over half listed grouper first on the survey and only two people did not list grouper at all. Clearly, changes to the grouper regulations are watched closely by and have ramifications for Tortugas fishing charters. Qualitatively, many operators were quite excited about changes to grouper regulations. A common theme was that recent changes to the red and black grouper bag limits were perceived as damaging to business. In the words of one operator, "who wants to go all that way to keep one grouper?"

*Figure 7.3. Changes to grouper catch regulations include Red Grouper (*Epinephelus morio*). Photo: NOAA CCFHR.*

Reserve and Park Rules

Both fishing and diving charter operators raised the issue of not being able to anchor or tie up anywhere overnight. To reach the Tortugas by sea mandates at least a seven hour boat ride (one way), so charter trips are, by necessity, multi-day excursions. However, while private boats can easily obtain permission via radio to tie up overnight to a mooring buoy in the TER or can run into national park waters to anchor, captains of charter boats with clients on board believe they are required to have a permit to anchor. Discussions with operators illustrated a perception that National Park Service (NPS) permits are difficult to obtain and the paperwork required to do so is cumbersome. There was definitely a sense that for-hire boats were being treated differently and less fairly than private boats with regard to tying up and anchoring. This complaint was separate from "safe harbor" issues, in which strong winds or other dangerous conditions requiring immediate anchorage. Interviews with park staff in June 2007 indicated some confusion as to the rules for charter operators wishing to enter park waters without a permit. These two factors were mentioned several times by operators as both an upsetting issue and a reason not to go the Tortugas.

Private Fishing, Non Consumptive Use and Advertising

To answer the question regarding fishing pressure associated with personal boats, meetings were held during the week of June 10, 2007, with one Tortugas ferry service captain and two ferry service employees, three DRTO rangers, one Key West dockmaster with Tortugas fishing experience, and the captain of the Florida Fish Finder, a 35 m party fishing vessels that makes multi-day trips to the Tortugas area. These individuals were asked to comment on the amount of boats they saw at any one time during their transit to or while in the Tortugas area. All respondents answered that they see few private fishing boats during the course of their voyages. A typical view was expressed by the ferry captain, who remarked that he sees "five to 10" private boats per week on his route. While more specific quantified results would be gained from an aerial survey that spans the four seasons, the findings reveal very light recreational fishing pressure occurring in the area near the TER and mirrors the findings of the 2000 SIA.

To answer the second and third questions (switching to non-consumptive uses and reserve-based marketing), two approaches were used. First, all of the above operators, as well as the president of the Keys Area Dive Association, were asked about businesses switching to non-consumptive use in the TER. Only two business operations, the Ultimate Getaway out of Ft. Meyers and the research vessel *Tiburon* out of Key West, were mentioned in these discussions. The second approach, a directory and online search, yielded the same businesses. However, while the owner of *Tiburon* does seem to have transitioned to research-only activities, Ultimate Getaway appears to still conduct some consumptive activities (although not in the TER), such as lobstering. With regard to using the reserve as an enticement to customers, it appears that Tortugas-based or associated businesses have yet to gear their messages towards the fact that they operate in the backyard of a relatively large marine reserve. Web sites and brochures only reference the DRTO and the history of the area. The words no-take, reserve, or protected area were not mentioned in any reviewed business literature.

Attitudes Towards the Reserve

The study of attitudes has been used in a variety of natural resource management situations, such as restoring wildlife (Brooks et al., 1999; Enck and Brown, 2002), and wildlife management activities (Bright, 1993; Bright and Barro, 2000; Teel et al., 2002; Lee and Miller, 2003; Koval and Mertig, 2004). However, McCleery et al. (2006) contend that many of the authors of natural resource management studies that utilize the attitude do not understand or have failed to properly communicate attitudes, attitudinal measurement, and the social psychological frameworks of attitudes, especially when examining attitude-behavior linkages.

Eagly and Chaiken (1993) define an attitude as, “a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor.” This definition has been supported by various investigators (e.g., Ajzen and Fishbein, 1980). Most attitudes studied by social psychologists, such as the ones presented in the present research, are probably learned (Eagly and Chaiken, 1993).

Attitudes towards the impact of the reserve were assessed directly and indirectly via several survey questions. Question 13 asked, “to what extent do you feel the creation of the TER has improved or harmed the quality of fishing in that area?” Seventeen people responded to this question. Seven individuals answered that they believe the reserve has “somewhat improved” the quality of fishing in the area. Five believe that there has been no change. Two believe that the reserve has “somewhat harmed” fishing in the area. Finally, one “did not know” for sure whether the reserve has had a positive or negative impact.

Respondents were about evenly split as to whether they fished near the boundaries of the reserve. Given examples from elsewhere of the “boundary effect,” where anglers and commercial fishing operators fish near the edge of a reserve’s borders in hopes of catching any bigger fish in the reserve, it seemed logical that the majority of respondents would have indicated they fished near the boundaries of the TER. However, there are reasons why some people would not answer this question truthfully, especially if they feel it will draw attention to them in the future or if there is uncertainty about whether this practice is illegal.

Finally, when responses to Question 4 (for each of the following, how would you rate the quality of fishing in or around the TER prior to its creation?) were compared to responses to Question 8 (for each of the following, how would you rate the quality of fishing near the TER today?), major differences were not indicated or observed. Several individuals stated that they feel the fishing is as good now as it always has been.

Economic Impacts

From the above summary, Leeworthy and Wiley (2000) expected that the maximum economic impacts of the reserve boundary designation to be small, and more likely negligible. Because of the small number of firms identified as operating in the proposed reserve area, and the small total impact of the reserve, any error in terms of having not included an operator in the original estimate is potentially large. For example, they found that only two operators provided lobster dive trips, so finding a single additional operator would increase the estimated number of participants by 50%.

Nine of the 12 businesses that were originally surveyed in the 2000 SIA were located. Of these nine, seven were contacted successfully. Without the ability to contact the additional five operators to see if they are still running operations in the area, it is presumptuous to conclude that they are out of business, and specifically

out of business due to the reserve. This makes comparison of current conditions to the pre-reserve designation conditions problematic. Interestingly, four operators that claimed to have run operations in the Tortugas area prior to the establishment of the reserve, but were not surveyed in 2000.

Of the fishing operations surveyed for this report, two did not operate in the Tortugas area prior to the reserve designation and do not do so now. Of the remaining operations, 10 operated prior to the designation and continue to operate today outside the reserve. Five that operated in the Tortugas area prior to the reserve no longer operate in the area, but these are almost completely replaced by the four operations that indicate that they are now operating in the Tortugas where they had not operated prior to the reserve designation.

The 2000 SIA found that potential economic losses would be small and that substitution rather than business closures would be the likely behavioral response to the TER. The 2006 discussions with these operators confirmed that this has indeed been the case. This finding, along with the findings discussed above, argued conclusively against a full recreation of the 2000 SIA.

DISCUSSION AND RECOMMENDATIONS

A re-analysis of the economic attributes of the Tortugas for-hire diving and fishing industry would provide little useful data to coastal marine resource managers in terms of understanding the consequences of creating the TER. Moreover, any new figures indicating a change pre and post TER would likely be misrepresented as being a result of the creation of the reserve when such a conclusion is not able to be drawn because of a lack of data on a wider range of socially-relevant variables. Data on many of these variables, discussed above, were not collected in the 2000 SIA. However, this information is important because it represents the social and economic drivers of resource use and provides the basis from which to understand and predict behavioral responses to economic, social and environmental changes.

This report finds that in 2006 the recreational economic impacts of reserve designation were minimal and had been offset by behavioral adjustments of operators and their clients. There is no indication that there was a major net change in the number of operators in the Dry Tortugas area, although some individual firms may have gone out of business. Even so, it would be difficult to state that the cause of this was the establishment of the reserve. Although many existing operators indicated in their response to the questionnaires that they would have preferred that the reserve was not created, they also indicate that the distance and remoteness of the reserve area is a major factor limiting activity in that area.

The results of this study point to a need to operate with a broader scope when conducting baseline human dimensions impact analyses of marine reserves. In addition to the issue of intervening variables, recent statutory changes, such as those to the Magnuson-Stevens Fishery Conservation Act that provide for (a) better inclusion of sport fishing data in decision making, and (b) mechanisms to reverse no-take zones if the objectives of the closure are achieved illustrate a changing paradigm in marine reserve designation and management processes. However, while the biological science underpinning marine reserve theory is still being debated (e.g., Jones, 2007; Tupper et al., 2002), the potential benefits of marine fishery reserves are being touted by managers and scientists (Murray et al., 1999; Roberts et al., 2001; Halpern and Warner, 2002) and it therefore appears likely that marine reserves will have a place in fishery and marine sanctuary management for the foreseeable future.

This continued use of marine reserves necessitates the creation of a framework that institutionalizes the collection of information regarding a broader suite of factors and issues that pertain to the for-hire and private recreational sectors. Such information will enable marine resource managers to better analyze and learn from marine reserve implementations. The issues of intervening variables, attitudes towards the effectiveness of the TER, user norms, and beliefs about reserve theory in general suggest that an analysis with a fairly strict economic focus is perhaps too limited in scope to use as a primary baseline for evaluating the impacts of designating marine reserves. While the 2000 SIA was comprehensive and well done in terms of economics, it ultimately proved of little value in understanding the changing nature of fishing and diving in the area that is now the TER. This is due to the unanticipated effects of the intervening variables noted.

For this reason, it is recommend that future social impact analyses be based on an interdisciplinary framework that includes both an economic component and a social component, and that this social component include a broad range of disciplines, such as sociology, social psychology, anthropology and recreation. This is especially important in cases where behavioral adjustments, such as substitution, are likely to confound a follow-up economic analysis. This framework could include pertinent elements of the National Marine Fisheries Service (NMFS) Social Impact Analysis assessment procedures (NOAA, 2007).

A combination of the traditional economic analysis and the NMFS assessment approach serves as a good model for quantifying and qualifying social conditions at the time of a reserve's designation because the interdisciplinary nature of such a framework will most probably be more responsive to and inclusive of a variety of factors that will likely prove important when evaluating impacts in the future. Specifically, the NMFS approach serves to gauge the social and cultural consequences of alternative fishery management actions or policies, determines social and cultural conditions likely to be affected by the regulatory action or policy, and project future social and cultural effects of continuing the status quo. Additionally, it considers the effects of:

1. Changes in resource availability;
2. Changes in fishing practices on fishermen, communities, fishing-related businesses;
3. Families and other social institutions;
4. Regulations and social norms of behavior; and
5. Social and cultural values

Furthermore, NMFS guidelines state that while descriptions of effects should be quantitative probabilities, this is not always possible. In these cases, conclusions should be discussed qualitatively rather than simply ignored because they are not easily enumerated or understood.

SUMMARY AND CONCLUSIONS

While a general distrust of government on the part of the fishing operators was observed, this study benefited from a high degree of cooperation among the sample. As the survey instrument illustrates, operators were asked about their past and recent trips to the Tortugas, what constraints exist for them with regard to making such trips, and what, if any, impacts the TER has had on their economic and social well-being.

There are three important findings from this study. The first is that there is little evidence to suggest that (a) there has been either a negative or positive economic impact of reserve designation on charter fishing and diving operations that operated in the study area prior to its creation, or (b) the reserve has been an economic barrier to business. Participation was extremely low, by any measure, prior to establishment of the reserve, and by all indicators remains low today. The issue of quantifying change in participation is not whether to express change in absolute numbers or percentages, but the fact that accurately measuring change and then attributing that change to the reserve is extremely difficult given the above described circumstances.

The surveys and interviews suggest that operators feel that diving and fishing is still as good as ever (but not significantly better) in the Tortugas region, and the operators who went to the study area prior to its designation as an ecological reserve have adapted to the closure via substitution. However, there was variance on the issue of general support for no-take fishery reserves. For example, while some stated that closing an area "must have some positive impact to the fish stocks," there were at least two people who found this idea baseless. In one case, it was termed "ridiculous."

The second important finding from this study is that in cases where substitution is an available option for operators, and where there are multiple economic and social variables that are unaccounted for, a straightforward before and after economic comparison will likely show little evidence of positive or negative impact due to a marine closure. Therefore, it is recommended future social impact analyses undertaken by NOAA include an interdisciplinary social science team. Such a team would be in a better position to build an analysis framework that would include collecting data on study area specific potentially intervening variables. This will allow for a

more detailed, holistic and meaningful comparison later. This study suggests several variables that may generalize to other geographic locations.

Thirdly, while marine resource managers hope that establishing marine reserves will have benefits, such as increased fish to catch and observe, to those who use and rely on the surrounding marine environment, the complexity of ecological systems and social variables, and the interplay between the two, can make quantifying such benefits difficult. For example, were fish biomass to increase substantially from the creation of the reserve, the local dispersal patterns of such biomass may not be well understood. How do storms and climate shifts factor in? How can benefits to the few private recreational anglers be quantified? If fish biomass increases but fuel prices or fewer customers force charter operators to stay closer to Key West, how will more fish in the Tortugas help them? A main problem here is that the reserve is so remote and difficult to access that it limits the ability to suggest that biophysical improvements in conditions within the reserve have led to more non-consumptive recreational use or benefits within the reserve boundaries. One of the goals in establishing the reserve was that it would (hopefully) improve abundance and diversity of stocks in the broader Florida Keys. It is even more difficult to prove that this has occurred, and then, a completely different scope of study is necessary to determine what the economic benefits and impacts of those improvements are.

It takes the right kind of business model, knowledge of the waters, the right business atmosphere, and the right regulatory conditions to make for-profit recreational fishing in the Tortugas feasible. Because of this, the number of for-hire dive and fishing operators utilizing the Tortugas area was small in 2000, and remains so today. There has been no large movement of operators into or out of this community. The reserve does not appear to have created any large-scale positive or negative impacts on for-hire recreational businesses that used the Tortugas area. This study relied on both quantitative and qualitative methods, but did not recreate the detailed economic analysis conducted as part of the 2000 SIA. While scale of activity and the net change in economic terms are important measures in marine reserve research, in the case of the TER these numbers are small and knowing the change in number of operations, as well as understanding the attitudes and beliefs of charter operators and the intervening variables noted, is sufficient. Conclusions and recommendations would not be changed by conducting a detailed economic analysis. For the reasons stated elsewhere, collecting and analyzing such information, stating that this actually represented a real change, and then attributing that change to the establishment of the reserve would go far beyond the ability of the data to draw those conclusions.

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Appendix I

Metadata for integrated bathymetric map of the Tortugas region (see Chapter 2).

sb_bath002

Metadata:

- Identification_Information
- Data_Quality_Information
- Spatial_Data_Organization_Information
- Spatial_Reference_Information
- Distribution_Information
- Metadata_Reference_Information

Identification_Information:
Citation:
Citation_Information:
Originator: University of Miami Rosenstiel School of Marine and Atmospheric Science
Originator: NOAA National Ocean Service, National Centers for Coastal Ocean Science
Publication_Date: March 9, 2007
Title:
sb_bath002
Geospatial_Data_Presentation_Form: raster digital data
Online_Linkage: \\10.123.1.12
\Biogeo\BIOGEO\Projects\Dry_Tort_IBA\GIS_Layers\Mapping\Bathymetry\South_Florida\ESRI_Grids\sb_bath002
Description:
Abstract:
Bathymetry data were compiled from 11 sources to generate composite bathymetry maps of South Florida at 0.002 degree resolution (~200 m). The main data source used for the South Florida region was the NOAA NOS Hydrographic Survey data set (see supplemental information) which was used as the starting base layer, and then other data sources were added to fill gaps. The resolution of these original data ranged from 100 to 300 m. This final composite layer has a geographic grid resolution of 0.002 degrees (~200 m).
Purpose:
This data set was compiled to develop a comprehensive bathymetry map of the Tortugas region to fill current data gaps and also provide the most up to date base layer for an Integrated Biogeographic Assessment of the Tortugas Region including the Tortugas Ecological Reserve and the Dry Tortugas National Park.
Supplemental_Information:
Sources of Bathymetric Data

[1] NOAA/NOS Hydrographic Surveys
Source: NOAA/National Geophysical Data Center, Boulder, Colorado.
Description: Depth soundings, NOS Hydrographic Survey Data, Version 4.0 Vol. 1&2.
Spatial coverage: Several discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth.
http://www.ngdc.noaa.gov/mgg/fliers/03mgg03.html

[2] Marine Trackline Geophysics
Source: National Geophysical Data Center, Boulder, Colorado.
Description: Depth soundings, Marine Trackline Geophysics, Version 4.0 Vol.1,2,&3.
Spatial coverage: Tracklines in the Tortugas region.
Variables: Latitude, Longitude, Depth.
http://www.ngdc.noaa.gov/mgg/fliers/03mgg02.html

[3] Two-Minute Gridded Global Relief Data.
Source: http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html
Spatial coverage: Global gridded in 2 minute resolution.
Variables: depth in gridded format.

[4] NMFS Acoustic Survey
Source: Chris Glendhill, NMFS Pascagoula
Description: Hydroacoustic survey of bathymetry.
Spatial coverage: Widely spaced acoustic tracklines in discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth.

[5] High Resolution Bathymetry of Florida Bay
Source: USGS http://sofia.usgs.gov/projects/bathymetry/
Spatial coverage: Florida Bay
Variables: X, Y, Z
This bathymetric data was collected in Florida Bay by the US Geological Survey, South Florida Place-Based Studies

Program using SANDS (System for Accurate Nearshore Depth Surveying). SANDS is a USGS developed, high precision bathymetric system which integrates depth soundings, boat motion, and GPS positioning needed for nearshore bathymetric mapping. Data acquisition occurred between 1995 and 1999 on a shallow 22' shallow draft boat. Processed data points are in X, Y, Z format and relative to the North American Datum of 1988 (NAVD88). Vertical control was derived from GPS data processed with Jet propulsion Laboratory GIPSY software. Horizontal and vertical accuracies are within ± 4 cm and ± 8 cm respectively.

[6] NOAA/NOS Hydrographic Surveys, multibeam 2000
Source: NOAA Silver Spring, MD.
Description: Depth soundings from multi-beam sonar survey conducted by NOAA/NOS
Hydrographic Teams (2000)
Spatial coverage: About 4 km2 around Sherwood Forest area of the Tortugas region.
Variables: Latitude, Longitude, Depth.

[7] NOAA/NOS Hydrographic Surveys, side-scan 1998
Source: NOAA Silver Spring, MD.
Description: Bathymetric and bottom substrate data from side-scan surveys conducted by NOAA/NOS hydrographic teams (1998). 116
Spatial coverage: Several discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth, Side-scan images.

[8] NOAA/NOS Hydrographic Surveys, side-scan 2000
Source: NOAA Silver Spring, MD.
Description: Bathymetric and bottom substrate data from side-scan surveys conducted by
NOAA/NOS hydrographic teams (2000).
Spatial coverage: Several discrete areas of the Tortugas region
Variables: Latitude, Longitude, Depth, Side-scan images.

[9] Multibeam data NOAA ship Whiting (2001-2002)
(NOS, Norfolk, Va),
Description: Depth soundings from multi-beam sonar survey conducted by NOAA/NOS
Hydrographic Teams.
Spatial coverage: Riley's Hump, south Tortugas Bank, the lope of north Tortugas Bank
Variables: Latitude, Longitude, Depth.

[10] Mulitbeam data NOAA ship Nancy Foster (2004)
Description: Depth soundings from multi-beam sonar survey conducted by NOAA Center for Coastal Fisheries and Habitat Research.
Spatial coverage: 16 study sites (about 1km x 4km each) from TD bank to the Park.
Variables: Latitude, Longitude, Depth.

[11] United States Geological Survey Center for Coastal and Watershed Studies, 2006, Dry Tortugas National Park EAARL Submarine/Subaerial/Merged Topography.
Description: Using airborne LIDAR to measure the submerged topography of the Dry Tortugas reef tract and Sub-aerial topography of land feature.
Spatial coverage: Most shallow water (less than 15 m) of the DTNP.
Variables: Latitude, Longitude, Depth.
Reference: Brock, J.C., Wright, C.W., Patterson, M., Nayegandhi, A., Patterson, J (2006). USGS-NASA_NPS EAARL topography - Dry Tortugas National Park: U.S. Geological Survey Open-File Report 2006-1244.

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Theme_Keyword_Thesaurus: REQUIRED: Reference to a formally registered thesaurus or a similar authoritative source of theme keywords.
Theme_Keyword: REQUIRED: Common-use word or phrase used to describe the subject of the data set.

Access_Constraints: Please cite any use of this data
Use_Constraints:
Note: NOT TO BE USED FOR NAVIGATION. These data were prepared by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed in this report, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. Any views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Although all data have been used by NOAA, no warranty, expressed or implied, is made by NOAA as to the accuracy of the data and/or related materials. The act of distribution shall not constitute any such warranty, and no responsibility is assumed by NOAA in the use of these data or related materials
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Jiangang Luo
Contact_Organization: University of Miami Rosenstiel School of Marine and Atmospheric Science
Contact_Address:
Address_Type: physical address
Address:
University of Miami
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Address:
4600 Rickenbacker Causeway
City: Miami
State_or_Province: FL
Postal_Code: 33149
Country: USA
Contact_Electronic_Mail_Address: jluo@rsmas.miami.edu
Data_Set_Credit:
University of Miami Rosenstiel School of Marine and Atmospheric Science
Native_Data_Set_Environment:
Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.2.1.1332

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Geographic_Coordinate_Units: Decimal degrees

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Altitude_System_Definition:
Altitude_Datum_Name: North American Vertical Datum of 1988
Altitude_Distance_Units: meters

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Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: C. Jeffrey
Contact_Organization: NOAA National Centers for Coastal Ocean Science
Contact_Address:
Address_Type: mailing address
Address:
1305 East West Hwy, N/SCI-1, SSMC-4
City: Silver Spring
State_or_Province: MD
Postal_Code: 20832
Country: USA
Contact_Voice_Telephone: (301) 713-3028 x 134
Hours_of_Service: 8:30 am to 3:30 pm
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Online_Linkage: http://www.esri.com/metadata/esriprof80.html
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Metadata for multibeam surveys of the Dry Tortugas Ecological Reserve. Data were collected by the NOAA Center for Coastal Fisheries and Habitat Research (CCFHR) and Geodynamics LLC and were used to develop an integrated bathymetric map for the region (see Chapter 2).

High-Resolution Multibeam Surveys of the Dry Tortugas Ecological Reserve: September 2004

Metadata also available as

Metadata:

Identification_Information:
  Citation:
    Citation_Information:
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      Publication_Date: 20041018
      Publication_Time: Unknown
      Title:
        High-Resolution Multibeam Surveys of the Dry Tortugas Ecological Reserve: September 2004
      Edition: First edition
      Geospatial_Data_Presentation_Form: model
      Series_Information:
        Series_Name:
          High-Resolution Multibeam Surveys of the Dry Tortugas Ecological Reserve: September 2004
      Publication_Information:
        Publication_Place: Pine Knoll Shores, North Carolina
        Publisher: Geodynamics
      Online_Linkage: www.geodynamicsgroup.com
      Larger_Work_Citation:
        Citation_Information:
          Originator:
            Geodynamics LLC under contract for the NOAA Center for Coastal Fisheries Habitat and Research
          Publication_Date: Unknown
          Title:
            High-Resolution Multibeam Surveys of the Dry Tortugas Ecological Reserve: September 2004
          Geospatial_Data_Presentation_Form: tabular digital data
  Description:
    Abstract:
      Hydrographic surveys using multibeam sonar provide detailed information of the seafloor which are used for nautical charting, geological investigations as well as high-resolution data for various coastal engineering projects (to name just a few

applications). When compared to traditional single beam surveys, modern multibeam technology allows for the acquisition of "100% bottom coverage" in a swath that is typically 3 to 4 times the water depth depending on the transducer configuration. This provides hundreds of more soundings per unit of time when compared to single beam technology. The final product of swath-based bathymetric surveys allow the end user to resolve features on the seafloor of varying size and frequency and to calculate a multitude of engineering parameters otherwise unattainable with single beam sonar. In addition, these spatially dense surveys are easily imported into a Geographic Information Systems (GIS) database that allow users to analyze various morphological, physical and environmental data from a single project specific database.

Geodynamics LLC was contracted by the NOAA Center for Coastal Fisheries Habitat and Research group in August of 2004 to perform detailed hydrographic surveys in support of habitat-based mapping of the Dry Tortugas Ecological Reserve and US National Park as described in the official SOW. These surveys made use of a Simrad EM3000 multibeam sonar system compensated with precise heading and motion reference instrumentation.

The principal objective of the following metadata is to outline detailed information pertaining to the collection and processing of high-resolution multibeam data by Geodynamics in September 2004.

Purpose:

Information pertaining to the purpose and use of these data should be directed to the project manager and team leader Mark Fonseca at the NOAA Center for Coastal Fisheries Habitat and Research (252)-728-8729 mark.fonseca@noaa.gov

Supplemental_Information:

High-resolution multibeam bathymetry data, collected as part of the NF-04-16-FK Cruise was collected secondarily to the overall goal of the cruise, biological monitoring of 30 stations in and around the Dry Tortugas Ecological Preserve.

For supplemental information concerning survey acquisition and processing details please refer to the directory labeled "Supplemental_QA_QC_Info" on the official data DVDs.

Multibeam data was collected with: Sonar: Simrad EM3000 transducer Heading: VT TSS Meridian Surveyor Motion: VT TSS DMS-05 Position: Trimble 5700 WAAS GPS Aquisition: TEI Isis Sonar Research Vessel: NOAA Ship Nancy Foster

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Ending_Date: 20030929
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Progress: Complete
Maintenance_and_Update_Frequency: Unknown
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Theme_Keyword: Dry Tortugas
Theme_Keyword: EM3000
Theme_Keyword: marine sediments
Theme_Keyword: sedimentos marinos
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Theme_Keyword: estudios
Theme_Keyword: pesquisas
Theme_Keyword: Coastal maps
Theme_Keyword: morphology
Theme:
Theme_Keyword_Thesaurus: Multibeam
Theme:
Theme_Keyword_Thesaurus: Hydrographic Survey
Place:
Place_Keyword_Thesaurus: Dry Tortugas, Florida
Place_Keyword: Dry Tortugas Ecological Preserve
Place_Keyword: Florida Keys National Marine Sanctuary

Access_Constraints:
All access to these data must first be cleared and or approved by the team leader and PI, Mark Fonseca at the NOAA Center for Coastal Fisheries Habitat and Research (252)-728-8729 mark.fonseca@noaa.gov. High resolution spatial bathymetric data collected in the Dry Tortugas by Geodynamics LLC are considered at this time to be confidential.
Use_Constraints:
Bathymetric data are NOT FOR NAVIGATIONAL USE. Geodynamics LLC and the NOAA Center for Coastal Fisheries Habitat and Research are not responsible for products (including but not limited to: maps, recession rates, models....) generated with these data that are not in accordance with proper scientific method. There is no warranty expressed or implied made by Geodynamics LLC and the NOAA Center for Coastal Fisheries Habitat and Research as to the accuracy of these data. Geodynamics LLC and the NOAA Center for Coastal Fisheries Habitat and Research assumes no liability for use of this data. The act of distribution shall not constitute any such warranty, and no responsibility is assumed by Geodynamics LLC and the NOAA Center for Coastal Fisheries Habitat and Research in the use of these data, software, or related materials.
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Chris Freeman
Contact_Organization: Geodynamics LLC
Contact_Position: Sr. Marine Geologist & President

Contact_Voice_Telephone: 252-247-5785
Contact_Facsimile_Telephone: N/A
Contact_Electronic_Mail_Address: chris@geodynamicsgroup.com
Hours_of_Service: 6:30am to 8:00pm
Data_Set_Credit: Geodynamics LLC
Security_Information:
Security_Classification_System: Data is considered classified
Security_Classification: Restricted
Security_Handling_Description: Please contact Mark Fonseca for access to these data
Native_Data_Set_Environment:
Microsoft Windows 2000 Version 5.0 (Build 2195) Service Pack 4; ESRI ArcCatalog 8.2.0.700

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Attribute_Accuracy:
Logical_Consistency_Report:
The minimum standards for multibeam echosounder sonar system resolution are set forth in the NOS Hydrographic Surveys, Specifications and Deliverables, and the USACE Hydrographic Survey Manual. Geodynamics maintains and operates the Simrad EM3000 Multibeam system from data aquisition to processing, such that the system can detect shoals that measure 2m x 2m horizontally and 1m vertically in depths of 40m or less. For depths greater than 40m the minimum size of detectable targets shall be 10% of the depth horizontal dimension and 5% of the depth for vertical dimensions.
Completeness_Report:
Multibeam suvey data collected for the High-Resolution Multibeam Surveys of the Dry Tortugas Ecological Reserve: September 2004 have undergone rigerous field and processing standards in accordance with the USACE Hydrographic Suvey Manual (2003) and the NOS Hydrographic Surveys, Specifications and Deliverables Manual (2003). The survey data described in the following metadata is complete and adequate for modeling and charting purposes.
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
Horizontal positioning was acquired with a Trimble 5700 WAAS enabled GPS system.
Quantitative_Horizontal_Positional_Accuracy_Assessment:
Horizontal_Positional_Accuracy_Value: Average <3m
Horizontal_Positional_Accuracy_Explanation: Published
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report:
See final report
Quantitative_Vertical_Positional_Accuracy_Assessment:
Vertical_Positional_Accuracy_Value: Average: <3m
Vertical_Positional_Accuracy_Explanation: Overall vertical accuracy is a combination of the inherent accuracy of WAAS enabled GPS, tidal measurements (taken from a NOAA extrapolated tide station), and sound velocity measurements.
Lineage:
Source_Information:
Type_of_Source_Media: DVD-ROM
Process_Step:
Process_Description:

The multibeam collects swath widths approximately 3.5 to 4 times the water depth. The portions of swath, mainly in the outer beams that exhibit areas of inconsistent data are clipped and not included in the final digital file. Sounding tracklines are generally parallel to each other and parallel to the contour. Sinuous lines and data aquired during turns are not included in the final processed data. To meet accuracy and resolution standards for measured depths specified in the USACE Hydrographic Surveying Manual and the NOS Hydrographic Surveys, Specifications and Deliverables Manual, measured echosounder depths were corrected for all departures from true depths attributable to the method of sounding or to faults in the measuring apparatus. These corrections are subdivided into four catagories, and are listed below in the sequence in which they were applied to the data.

1. Instrument error corrections: account for the sources of error related to the sounding equipment itself.

2. Draft corrections: were added to the observed soundings to account for the depth of the echosounder below the water surface.

3. Velocity of sound correctors: were applied to the soundings to compensate for the fact that echosounders may only display depths based on an assumed sound velocity profiile while the true velocity may vary in time and space.

4. Heave, pitch, roll, heading and navigation latency corrections: were applied to the multibeam soundings to correct for the effect of vessel motion caused by waves and swells, the error in the vessel's heading, and the time delay from the moment the position is measured until the data is received by the GPS reciever.

Multibeam Data Processing Steps in TEI software: -Data undergoes cleaning or snipping of bad or spiky pings in ISIS (if necessary) -Data files (XTF) are imported into Bathy Pro. -Map Settings (projection and resolutions) -Sensor Geometry (applies the static adjustments/offsets determines in the patch test to the data) -Data are filtered for bad pings, excessive speed and spikes in Bathy Pro -Tide File (RTK or Regular is applied) -Sound Velocity is applied -Fill Gaps and Smoothing filters may be applied -Generate isocurves and/or soundings.

Source_Used_Citation_Abbreviation: C:\DOCUME~1\ADMINI~1\LOCALS~1\Temp\xml2.tmp
Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: David Bernstein
Contact_Organization: Geodynamics
Contact_Position: Marine Geologist & Mapping Specialist
Contact_Voice_Telephone: 843-997-9111
Contact_Facsimile_Telephone: N/A
Contact_Electronic_Mail_Address: dave@geodynamicsgroup.com
Hours_of_Service: 6:30am to 8:00pm

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Point

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Local:
Local_Description:
UTM Zone_17 Units :meters
Local_Georeference_Information: UTM Zone 17 N
Geodetic_Model:
Horizontal_Datum_Name: World Geodetic System 1984
Ellipsoid_Name: WGS 84
Semi-major_Axis: 6378137.0000
Denominator_of_Flattening_Ratio: 298.257223563

Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
Altitude_Datum_Name: Mean-Lower-Low-Water
Altitude_Resolution: unknown
Altitude_Distance_Units: Meters
Altitude_Encoding_Method:
Explicit elevation coordinate included with horizontal coordinates
Depth_System_Definition:
Depth_Datum_Name: Mean-Lower-Low-Water
Depth_Resolution: unknown
Depth_Distance_Units: Meters
Depth_Encoding_Method: Explicit depth coordinate included with horizontal coordinates

---

Entity_and_Attribute_Information:
Overview_Description:

Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Mark Fonseca
Contact_Organization: NOAA Center for Coastal Fisheries Habitat and Research, Beaufort, North Carolina
Contact_Position: Team Leader (PI) - Applied Ecology and Restoration Research
Contact_Address:
Address_Type: physical address
Address: 101 Pivers Island Rd
City: Beaufort
State_or_Province: NC
Postal_Code: 28516-9722
Country: USA
Contact_Voice_Telephone: 252-728-8729

Contact_Facsimile_Telephone: 252-728-8784
*Contact_Electronic_Mail_Address:*mark.fonseca@noaa.gov
Hours_of_Service: unknown
Resource_Description:
Downloadable Data DVD or CD ROM
Distribution_Liability:
Data on this DVD should not be distributed without proper clearance from the NOAA Center for Coastal Fisheries Habitat and Research lab as described in the use contraints. Users of these data should refer to the orginal sources to review the limitations of these data for specific studies and applications. Users assume the entire risk related to using these data. The NOAA Center for Coastal Fisheries Habitat and Research lab and Geodynamics LLC disclaims any and all warranties, whether expressed or implied, including (without limitation) any implied warranties of merchantability or fitness for a particular purpose. In no event will the NOAA Center for Coastal Fisheries Habitat and Research lab or Geodynamics LLC be liable to you or to any third party for direct, indirect, incidental, consequential, special or exemplary damages or lost profit resulting from any use or misuse of these data. References to any specific commercial products, process, or service trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the NOAA Center for Coastal Fisheries Habitat and Research lab or Geodynamics LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the NOAA Center for Coastal Fisheries Habitat and Research lab or Geodynamics LLC, and shall not be used for advertising or product endorsement purposes.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ASCII
File_Decompression_Technique: WinZip 8.0 or later
Digital_Transfer_Option:
Online_Option:
Online_Computer_and_Operating_System: Microsoft Windows based OS or Mac OS X or later
Offline_Option:
Offline_Media: CD-ROM or DVD
Recording_Format: ASCII
Fees: unknown
Ordering_Instructions:
Please contact Mark Fonseca at the NOAA Center for Coastal Fisheries Habitat and Research Lab
Turnaround: unknown
Custom_Order_Process:
Please contact Mark Fonseca at the NOAA Center for Coastal Fisheries Habitat and Research Lab

---

Metadata_Reference_Information:
Metadata_Date: 20041018
Metadata_Review_Date: 20041018
Metadata_Future_Review_Date: unknown
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Chris Freeman or David Bernstein

Contact_Organization: Geodynamics LLC
Contact_Address:
Address_Type: Mailing and Physical Address
Address: 152 Hawthorne Drive
City: Pine Knoll Shores
State_or_Province: NC
Postal_Code: 28512
Country: USA
Contact_Voice_Telephone: 252-247-5785
Contact_Facsimile_Telephone: N/A
Contact_Electronic_Mail_Address: chris@geodynamicsgroup.com
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Access_Constraints:
please contact Chris Freeman or David Bernstein before altering these metadata
Metadata_Use_Constraints:
There are no use constraints on this metadata. However, processed multibeam data should not be circulated without this metadata!
Metadata_Security_Information:
Metadata_Security_Classification: Unclassified
Metadata_Extensions:
Online_Linkage:
<http://www.esri.com/metadata/esriprof80.html> &
<http://edcw2ks40.cr.usgs.gov/metalite/>
Profile_Name: ESRI Metadata Profile and the USGS metalite profile
Metadata_Extensions:
Online_Linkage: <http://www.esri.com/metadata/esriprof80.html>
Profile_Name: ESRI Metadata Profile

Generated by mp version 2.7.3 on Thu Jan 29 16:29:27 2004

geodynamics COMPLEX COASTAL CHANGE MADE CLEAR

About the Data:

1. For the information on this document and more detailed information about multibeam data acquired during the NF-04-16-FK cruise, please see the FGDC metadata found on the data DVD.

2. Multibeam data acquisition was planned in 2 ways to accomplish survey coverage over the 30 monitoring stations specified in the SOW. First, groups of stations were created, by Geodynamics and the NOAA Beaufort Lab in order to gain more coverage and make the surveys more efficient in time. The following groups were made and named in no specific manner;

Survey Group	Stations Included
S1	ON6772, OS7265, OS7675
S2	ON5527, ON5842
S3	OS6731, PS6493, PS6108
S4	RS9042, RS9162, RS10262
S5	RN8924, RN10105, RS10529
S6	RN9498, RN9807
S7	PN3120, PN3275
S8	ON11460, ON12379
S9	PN1136, PN690, PN632
SWC	Southwest Channel (for image groundtruthing)

   The remaining 7 monitoring stations were surveyed individually with a smaller coverage area surveyed around the single station (approximately 0.5 km^2).

3. Backscatter (snippet data) simultaneously collected with the EM3000 Multibeam system was processed separately from the multibeam bathymetry at 0.50m resolution. This data, in GeoTif format, represents amplitude returns from the sonar. The guide below can be used for general interpretation of each individual GeoTif image, as histograms between images may be different.

   Darker Color = lower amplitude return = low backscatter = softer bottom
   Lighter Color = higher amplitude return = high backscatter = harder bottom

4. Data / Directory Structure

DVD 1

- **NF-04-16-FK_1**
  - Dry_Tortugas_1
    - DATA
      - Multibeam_Bathy
        - S1
          - RAW
          - chart_soundings
          - grid_soundings
        - S2
          - RAW
          - chart_soundings
          - grid_soundings
        - S3
          - RAW
          - chart_soundings
          - grid_soundings
        - S4
          - RAW
          - chart_soundings
          - grid_soundings
        - S5
          - RAW
          - chart_soundings
          - grid_soundings

DVD 2

- **NF-04-16-FK_2**
  - Dry_Tortugas_2
    - DATA
      - Arc_Grids
      - Backscatter_TIFs
      - Multibeam_Bathy
        - ON94
          - RAW
          - chart_soundings
          - grid_soundings
        - OS1864
        - PS2780
        - PS3926
        - PS4671
        - RN1915
        - RS8233
        - S6
        - S7
        - S8
        - S9
        - SWC
      - Shapefiles
    - Final_Report
    - Imagery
    - Metadata
    - Supplemental_QA_QC_Info
      - Daily_logs
      - Processing_notes

Metadata for the coral reef and hardbottom areas in the Tortugas Ecological Reserve Study Area that were mapped by the Univeristy of Miami Rosenstiel School of Marine Science, NOAA Southeast Fisheries Science Center and the NOAA National Undersea Research Program. For completed map, see Chapter 2, Figure 2.1.

gridwithnurc

Metadata:

Identification_Information:
  Citation:
    Citation_Information:
    Originator: University of Miami Rosenstiel School of Marine and Atmospheric Science
    Publication_Date: March 9, 2007
    Title:
    gridwithnurc
    Geospatial_Data_Presentation_Form: vector digital data
    Online_Linkage:
    \\10.123.1.12\Biogeo\BIOGEO\Projects\Dry_Tort_IBA\GIS_Layers\Mapping\Benthic_habitat\gridwithnurc.shp
Description:
  Abstract:
    This data set was developed as part of the Tortugas Integrated Assessment project. Existing digital data sets were synthesized to generate the most up-to-date comprehensive maps of the Tortugas region to fill current data gaps and also provide base layers for the Integrated Biogeographic Assessment study. The University of Miami's Rosenstiel School of Marine and Atmospheric Science (UM-RSMAS) has been developing a detailed digital benthic map of coral reef and hard-bottom habitats for the Tortugas region by synthesizing data from a variety of technologies including bathymetric surveys; side-scan sonar, multibeam, and LIDAR magery; aerial photogrammetry; existing habitat maps; and in situ visual surveys (Franklin et at., 2003). The classification scheme used by UM-RSMAS is based on habitat relief and patchiness and describes nine hard-bottom and coral reef habitats encountered at depths from 1 to 33 m (Franklin et al., 2003). For this project, UM-RSMAS continued iteratively updating its 200 x 200m grid benthic map with in-situ field data collected by divers during 2006, and with additional data sets (multibeam sonar and satellite imagery and in-situ benthic characterization) from NCCOS' Center for Fisheries and Habitat Research. Previous habitat maps (e.g., NOAA and FMRI 1998) were limited to shallow-water (< 20 m depth) soft-sediment, coral reef, and hard-bottom habitats within Dry Tortugas National Park and did not include deeper areas such as the Tortugas Bank, now partially contained within no-take marine protected area boundaries. The current map produced during this project has expanded the mapped areas of the Tortugas region to include Riley's Hump, Tortugas Bank, and other less than 33 m deep between the Marquesas and Dry Tortugas National Park. The total area mapped by UM-RSMAS is 35,560.4254 ha compared with 10,032.8653 ha mapped by FMRI and NOAA in 1998.

  Purpose:
    This data set was created to provide a foundation for habitat-based stratified random sampling design for fisheries independent monitoring program for Coral reef fishes in the Florida Keys including the Tortugas
  Region

The data set was also created to provide the most comprehensive and up-to-date base GIS layers for the NOAA funded Integrated Assessment of Reef fishes in the Tortugas region.

Supplemental_Information:

This data set was created by UM-RSMAS scientists to build upon previous efforts to develop benthic maps for the Tortugas region. Initial mapping efforts by UM-RSMAS are described in detail in (Franklin et al., 2003). The full citation and abstract of the paper are provided below.

Fanklin, E. C., J. S. Ault, S. G. Smith, J. Luo, G. A. Meester, and G. A. Diaz. 2003. Benthic habitat mapping in the Tortugas region, Florida. Marine Geodesy 26:19-34.

Abstract:

Concern about declining trends in coral reef habitats and reef fish stocks in the Florida Keys contributed to the implementation of a network of no-take marine protected areas in 1997. In support of the efforts of the Dry Tortugas National Park and Florida Keys National Marine Sanctuary to implement additional no-take areas in the Tortugas region in 2001, we expanded the scale of our fisheries independent monitoring programfor coral reef fishes in the region. To provide a foundation for the habitat-based, stratified random sampling design of the program, we created a digital benthic habitat map of coral reef and hard-bottom habitats in a geographic information system by synthesizing data from bathymetric surveys, side-scan sonar imagery, aerial photogrammetry, existing habitat maps, and in situ visual surveys. Existing habitat maps prior to 1999 were limited to shallow-water (< 20 m depth) soft-sediment, coral reef, and hard-bottom habitats within Dry Tortugas National Park and did not include deeper areas such as the Tortugas Bank, now partially contained within no-take marine protected area boundaries. From diver observations made during the 1999 survey, we developed a classification scheme based on habitat relief and patchiness to describe nine hard-bottom and coral reef habitats encountered from 1–33 m depth. We provide estimates of area by habitat type for no-take marine protected areas in the Tortugas region. Updated information on the spatial distribution and characteristics of benthic habitats will be used to guide future monitoring, assessment, and management activities in the region. Significant data gaps still exist for the western area of the Florida Keys National Marine Sanctuary and are a priority for future research. Data from mapping activities by the NOAA Center for Coastal Fisheries and Habitat Research (CCFHR) in the Tortugas region were also utilized in the Tortugas Integrated Assessment project and in the creation of this data set. Benthic mapping by NOAA CCFHR include towed underwater video, side-scan and multi-beam sonar, aerial photography, and satellite imagery (IKONOS and QuickBird). These mapping activities are described in detail on page 6 and pages 9 to 15 of the NOAA Technical Memorandum NOS NCCOS 22 (Fonseca et al., 2006). The full citation and a summary of the mapping methods used by CCFHR are provided below.

Fonseca, M. S., A. V. Uhrin, C. A. Currin, J. S. Burke, D. W. Field, C. A. Addison, L. L. Wood, G. A. Piniak, T. S. Viehman, and C. S. Bonn. 2006. Ongoing Monitoring of Tortugas Ecological Reserve: Assessing the Consequences of Reserve Designation. NOAA Technical Memorandum NOS NCCOS 22. 48 pp.

Fine-Scale Mapping:- From 2001 – 2005, detailed mapping of benthic composition was conducted at sub-centimeter resolution at each permanent station. Divers were deployed at randomly selected permanent stations to conduct video or photo transects of benthic habitat and coral presence/absence surveys. Small launches navigated to each station using DGPS (Trimble GPS Pathfinder Pro XR/XRS). Divers used a digital video camera (SONY DCR TRV900/1000 MiniDV Handycam® camcorder) or a digital still camera (Olympus C-8080 Zoom) contained in an underwater housing with lighting unit, to record the substrate along the length of each transect. Video collection techniques are based on

those used by the Coral Reef Evaluation and Monitoring Project (CREMP) at Florida Wildlife Research Institute. A SENSUS PRO (ReefNet) dive data recorder affixed to the camera housing recorded a continuous depth profile for the duration of the video transect.

Coarse-Scale Mapping:- Benthic habitat mapping of permanent stations was conducted with a suite of technologies. A MiniBAT® tow body housing a downward facing SeaViewer® color Sea-Drop camera linked to a real-time differential GPS system was used to videotape the seafloor at 5 to 8 m resolution. At each station, 0.25-nautical-mile "S" turns were made with the MiniBAT® at the interface between sand and coral, running parallel to the depth contour and normal to three parallel track lines. The exact time and location along each transect was stamped onto the video with the Horita® GPT-50 GPS video titler linked to a Trimble GPS Pathfinder Pro XR/XRS. Track lines were recorded with Trimble ASPEN® software. In 2002 and 2003, stations were additionally mapped with a Sport Scan® side-scan sonar unit; a maximum of three parallel tracks (~ 500 - 1000 m long) were made parallel to the reef-sand ecotone. CCFHR has acquired new aerial photography for the Dry Tortugas National Park and satellite imagery (IKONOS and QuickBird) for the area around Fort Jefferson and have visited over three hundred random points for ground truthing. The new imagery is being used to update the NOAA-FMRI benthic map that was based on aerial photography taken in 1991. In 2004, high-resolution hydrographic surveys of the 30 permanent stations was conducted with a Simrad EM3000 multi-beam echo-sounder, which was pole-mounted approximately 4 m below the sear's surface. The sonar system produced a swath of sonar approximately 3.5 to 4 times the water depth and collected approximately 400 soundings per square meter.

Sources of Bathymetric Data used for benthic habitat mapping of the Tortugas region

[1] NOAA/NOS Hydrographic Surveys
Source: NOAA/National Geophysical Data Center, Boulder, Colorado.
Description: Depth soundings, NOS Hydrographic Survey Data, Version 4.0 Vol. 1&2.
Spatial coverage: Several discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth.
http://www.ngdc.noaa.gov/mgg/fliers/03mgg03.html

[2] Marine Trackline Geophysics
Source: National Geophysical Data Center, Boulder, Colorado.
Description: Depth soundings, Marine Trackline Geophysics, Version 4.0 Vol.1,2,&3.
Spatial coverage: Tracklines in the Tortugas region.
Variables: Latitude, Longitude, Depth.
http://www.ngdc.noaa.gov/mgg/fliers/03mgg02.html

[3] Two-Minute Gridded Global Relief Data.
Source: http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html
Spatial coverage: Global gridded in 2 minute resolution.
Variables: depth in gridded format.

[4] NMFS Acoustic Survey
Source: Chris Glendhill, NMFS Pascagoula
Description: Hydroacoustic survey of bathymetry.
Spatial coverage: Widely spaced acoustic tracklines in discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth.

[5] High Resolution Bathymetry of Florida Bay
Source: USGS http://sofia.usgs.gov/projects/bathymetry/
Spatial coverage: Florida Bay

Variables: X, Y, Z

This bathymetric data was collected in Florida Bay by the US Geological Survey, South Florida Place-Based Studies Program using SANDS (System for Accurate Nearshore Depth Surveying). SANDS is a USGS developed, high precision bathymetric system which integrates depth soundings, boat motion, and GPS positioning needed for nearshore bathymetric mapping. Data acquisition occurred between 1995 and 1999 on a shallow 22' shallow draft boat. Processed data points are in X, Y, Z format and relative to the North American Datum of 1988 (NAVD88). Vertical control was derived from GPS data processed with Jet propulsion Laboratory GIPSY software. Horizontal and vertical accuracies are within ± 4 cm and ± 8 cm respectively.

[6] NOAA/NOS Hydrographic Surveys, multibeam 2000
Source: NOAA Silver Spring, MD.
Description: Depth soundings from multi-beam sonar survey conducted by NOAA/NOS Hydrographic Teams (2000)
Spatial coverage: About 4 km2 around Sherwood Forest area of the Tortugas region.
Variables: Latitude, Longitude, Depth.

[7] NOAA/NOS Hydrographic Surveys, side-scan 1998
Source: NOAA Silver Spring, MD.
Description: Bathymetric and bottom substrate data from side-scan surveys conducted by NOAA/NOS
hydrographic teams (1998). 116
Spatial coverage: Several discrete areas of the Tortugas region.
Variables: Latitude, Longitude, Depth, Side-scan images.

[8] NOAA/NOS Hydrographic Surveys, side-scan 2000
Source: NOAA Silver Spring, MD.
Description: Bathymetric and bottom substrate data from side-scan surveys conducted by NOAA/NOS hydrographic teams (2000).
Spatial coverage: Several discrete areas of the Tortugas region
Variables: Latitude, Longitude, Depth, Side-scan images.

[9] Multibeam data NOAA ship Whiting (2001-2002)
(NOS, Norfolk, Va),
Description: Depth soundings from multi-beam sonar survey conducted by NOAA/NOS Hydrographic Teams.
Spatial coverage: Riley's Hump, south Tortugas Bank, the lope of north Tortugas Bank
Variables: Latitude, Longitude, Depth.

[10] Mulitbeam data NOAA ship Nancy Foster (2004)
Description: Depth soundings from multi-beam sonar survey conducted by NOAA Center for Coastal
Fisheries and Habitat Research.
Spatial coverage: 16 study sites (about 1km x 4km each) from TD bank to the Park.
Variables: Latitude, Longitude, Depth.

[11] United States Geological Survey Center for Coastal and Watershed Studies, 2006, Dry Tortugas National Park EAARL Submarine/Subaerial/Merged Topography.
Description: Using airborne LIDAR to measure the submerged topography of the Dry Tortugas reef tract and Sub-aerial topography of land feature.
Spatial coverage: Most shallow water (less than 15 m) of the DTNP.
Variables: Latitude, Longitude, Depth.
Reference: Brock, J.C., Wright, C.W., Patterson, M., Nayegandhi, A., Patterson, J (2006).

NASA_NPS EAARL topography - Dry Tortugas National Park: U.S. Geological Survey Open-File Report 2006-1244.

Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 1994
Ending_Date: 2006

Currentness_Reference:
ground condition

Status:
Progress: In work
Maintenance_and_Update_Frequency: As needed

Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -83.136940
East_Bounding_Coordinate: -80.057045
North_Bounding_Coordinate: 25.936363
South_Bounding_Coordinate: 24.357536
Keywords:
Theme:
Theme_Keyword_Thesaurus: REQUIRED: Reference to a formally registered thesaurus or a similar
authoritative source of theme keywords.
Theme_Keyword: coral reefs
Theme_Keyword: marine protected areas
Theme_Keyword: essential fish habitat
Theme_Keyword: benthic maps
Theme_Keyword: Benthic habitatat
Theme_Keyword: Mapping
Place:
Place_Keyword: Dry Tortugas National Park
Place_Keyword: Florida Keys National Marine Sanctuary
Place_Keyword: South Florida
Place_Keyword: Florida Keys
Stratum:
Stratum_Keyword: coral reefs
Stratum_Keyword: hardbottom

Access_Constraints: Please cite any use of this data
Use_Constraints:
Note: NOT TO BE USED FOR NAVIGATION. These data were prepared by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed in this report, or represents that its use would not infringe privately owned rights. Reference therein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. Any views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Although all data have been used by NOAA, no warranty, expressed or implied, is made by NOAA as to the accuracy of the data and/or related materials. The act of distribution shall not constitute any such warranty, and no responsibility is assumed by NOAA in the use of these data or related materials.

Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Steve Smith
Contact_Organization: University of Miami Rosenstiel School of Marine and Atmospheric Science
Contact_Address:
Address_Type: mailing and physical address
Address:
University of Miami
Address:
Rosenstiel School of Marine and Atmospheric Science
Address:
Division of Marine Biology and Fisheries
Address:
4600 Rickenbacker Causeway
City: Miami
State_or_Province: FL
Postal_Code: 33149
Country: USA

Native_Data_Set_Environment:
Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI ArcCatalog 9.2.1.1332

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report:
UM-RSMAS scientists relied on the integrity of the original data used for this project. To create this digital benthic habitat, UM-RSMAS created, integrated, and manipulated several data sets using either ESRI Arcview°R 3.2, Arc/INFO°R 7.2, or RSI Interactive Data Language°R 4.0 (IDL) within a PC and UNIX GIS. Detailed descriptions of the data types used are provided in the supplemental information section of this document. The data sets represented the best available information for the region and were mostly nonoverlapping in time or space. Although the data sets were collected over a period of many 10 years, coral reef formations can persist for decades or centuries and remain fairly stable in position over time. Area estimates of habitats were made in the GIS using an Albers Equal Area projection (datum NAD83) with latitude of origin of 24.0, standard parallels of 24.0 and 31.5, central meridian of 84.0, false easting of 400,000.0 and false northing of 0.0 (Snyder 1987). More details are given in Franklin et al. (2003).

Logical_Consistency_Report:
The data appear logically consistent
Completeness_Report:
A review of the digital data to ensure line and attribute completeness was part of the QC process (See process step)
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
The basis for the development of this habitat map was the thematic layer and classification scheme previously created by the Florida Marine Research Institute (FMRI) from the interpretation of aerial photographic surveys performed between December 1991 and April 1992. The FMRI classification includes 22 categories

describing coral reef, seagrass beds, hard bottom, and sand/rock benthic substrates, generally limited to depths of less than 10 m. UM-RSMAS scientists redescribed a subset of the FMRI habitat categories with an updated habitat classification scheme that described nine habitat classes and included a easure of habitat relief and patchiness.

The nominal photo scale of the source photography was 1:48,000 (FMRI 1998). The vertical and horizontal accuracy of identifiable objects in the photographs were within 2 m and between 5 m to 10 m, respectively.

Feature boundaries delineating habitats have an estimated vertical accuracy of 3 m and horizontal accuracy of 5 m to 10 m, respectively. The horizontal accuracy of easily discernable habitat boundaries such as the transition between a rocky outcrop to a sand bottom is estimated to be 5 m, while the horizontal accuracy of the boundary between lowrelief hard bottom and patchy hard-bottom in sand is estimated to be 10 m. More details are given in Franklin et al. [(2003), see the supplemental information section of this document for a citation of this reference].

Lineage:

Process_Step:

Process_Description:

UM-RSMAS scientists developed and refined a classification scheme based primarily on geomorphological characteristics of benthic habitats for the Tortugas region during the 1999 and 2000 surveys (Table 2 in Franklin et al., 2003). Previous classification schemes (Agassiz 1883; Davis 1982; FMRI 1998; Jaap 1984; Shinn et al. 1989) for the Florida Keys were reviewed during development of the new classification. Revisions to the nomenclature of the FMRI benthic categories (1998) for the DTNP were made based upon diver observations of the habitats during the 1999 surveys. Several of the deeper bank habitat types such as reef terrace and pinnacle reefs were previously undescribed for the Florida Keys (Miller et al. 2001). Based on the visual surveys and literature review, UM-RSMAS described 12 habitat types encountered in the Tortugas region. Coral reef and hard-bottom habitats were distinguished by two main features: (1) the degree of "patchiness" (i.e., contiguous hard substrate vs. reef patches interspersed with sand), and (2) hard substrate vertical relief and complexity. The degree of habitat patchiness is determined by observing a low (< 30%), medium (33-66%), or high (> 67%) ratio of consolidated hard-bottom to sand bottom. Habitat relief is distinguished by low (<0.5 m), medium (0.5-2.0 m), or high (>2.0 m) levels of vertical relief and associated complexity (Figure 5a, Franklin et al., 2003). Nine coral reef and hard-bottom habitat types were encountered: (1) patchy hard-bottom in sand, (2) low-relief hard-bottom, (3) low-relief spur and groove, (4) rocky outcrops, (5) patch reefs, (6) medium profile reef, (7) high-relief spur and groove, (8) reef terrace, and (9) pinnacle reefs (Figure 5b, Franklin et al., 2003). We also encountered sand bottom, seagrass, and rubble. Using the updated classification scheme, further refinement of the regional map included the translation of existing habitat polygons and the addition of newly described habitat categories. Additionally, polygons were added for the new sites that were visited outside the domain of the mapped area. Feature boundaries delineating habitats have an estimated vertical accuracy of 3 m and horizontal accuracy of 5 m to 10 m, respectively. The horizontal accuracy of easily discernable habitat boundaries such as the transition between a rocky outcrop to a sand bottom is estimated to be 5 m, while the horizontal accuracy of the boundary between low-relief hard bottom and patchy hard-bottom in sand is estimated to be 10 m. See supplementary Information also.

Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Steve G. Smith
Contact_Organization: University of Miami Rosenstiel School of Marine and Atmospheric
Science
Contact_Electronic_Mail_Address: steve.smith@rsmas.miami.edu

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: G-polygon
Point_and_Vector_Object_Count: 362187

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Geographic:
Latitude_Resolution: 0.000000
Longitude_Resolution: 0.000000
Geographic_Coordinate_Units: Decimal degrees
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: gridwithnurc
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Attribute_Label: FID
Attribute_Definition:
Internal feature number.
Attribute_Definition_Source:
ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
Sequential unique whole numbers that are automatically generated.

Attribute:
Attribute_Label: Shape
Attribute_Definition:
Feature geometry.
Attribute_Definition_Source:
ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
Coordinates defining the features.

Attribute:
Attribute_Label: GRID_
Attribute_Definition:
Unique ID of 200 x 200 meter grid cell
Attribute_Definition_Source:
UM-RSMAS

Attribute:
Attribute_Label: REGION
Attribute:
Attribute_Label: SUBREG
Attribute:
Attribute_Label: SPA
Attribute:
Attribute_Label: NURCHAB
Attribute_Definition_Source:
Franklin et al., 2003. Benthic Habitat Mapping in the Tortugas Region, Florida. Marine Geodesy 26:19-34.
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: 1
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Patchy hard-bottom: Sand plains with patches of hard-bottom; Low vertical relief (< 0.5 m) and complexity
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Enumerated_Domain_Value: 2
Enumerated_Domain_Value_Definition:
Low-relief hard-bottom: Contiguous hard-bottom substrate; Low structural complexity and relief; Usually dominated by gorgonians
Enumerated_Domain:
Enumerated_Domain_Value: 3
Enumerated_Domain_Value_Definition:
Rocky outcrop: Hard-bottom aggregations bounded by sand; Moderate vertical relief (0.5-2.0 m)
Enumerated_Domain:
Enumerated_Domain_Value: 4
Enumerated_Domain_Value_Definition:
Pinnacle reef: High-complexity patches rising to 15 m depth; Surrounded by sand plains
Enumerated_Domain:
Enumerated_Domain_Value: 5
Enumerated_Domain_Value_Definition:
Reef terrace: High-relief (>2 m), contiguous reef habitat; Abundant and large mushroom and platy corals; Primarily located on western sides of banks
Enumerated_Domain:
Enumerated_Domain_Value: 6
Enumerated_Domain_Value_Definition:
Patch reef: Aggregate or clusters of dome-shaped reefs; Interspersed with sand; Moderate vertical relief and substrate complexity; similar to patch reefs in the Florida Keys
Enumerated_Domain:
Enumerated_Domain_Value: 7
Enumerated_Domain_Value_Definition:
Medium-profile reef: Contiguous reef substrate; moderate vertical relief and complexity

Enumerated_Domain:
Enumerated_Domain_Value: 8
Enumerated_Domain_Value_Definition:
Low-relief spur: Low-profile coralline spurs separated groove by sand grooves; broad spurs up to 5 m wide with low vertical relief
Enumerated_Domain:
Enumerated_Domain_Value: 9
Enumerated_Domain_Value_Definition:
High-relief spur and groove: High-profile coralline spurs separated by sand grooves; High vertical relief (>2 m) and complexity; Diverse assemblage of reef benthos
Attribute:
Attribute_Label: DEPCAT
Attribute_Definition:
Depth class
Attribute:
Attribute_Label: DDLON
Attribute_Definition:
Decimal Degrees Longitude
Attribute:
Attribute_Label: DDLAT
Attribute_Definition:
Decimal Degrees Latitude
Attribute:
Attribute_Label: GRID

Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 46.965

Metadata_Reference_Information:
Metadata_Date: 20070816
Metadata_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: C. Jeffrey
Contact_Organization: NOAA National Centers for Coastal Ocean Science
Contact_Address:
Address_Type: mailing and physical address
Address:
1305 East West Hwy, N/SCI-1, SSMC-4
City: Silver Spring
State_or_Province: MD
Postal_Code: 20910
Country: USA
Contact_Voice_Telephone: (301) 713-3028 x 134
Contact_Electronic_Mail_Address: chris.jeffrey@noaa.gov
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time

Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html
Profile_Name: ESRI Metadata Profile

Appendix II

From 2001-2005, the NCCOS Center for Coastal Fisheries and Habitat Research (CCFHR) has conducted annual surveys at 30 permanent stations in the Dry Tortugas region to collect data on the area's fish and benthic communities. The permanent stations included 10 stations within Tortugas Ecological Reserve (TER or "Reserve"), 10 stations within Dry Tortugas National Park (DRTO or "Park"), and 10 stations outside of park and reserve management zones ("Out"). The 30 stations represent not only different management schemes, but also different locations on the bank, exposure to prevailing currents from the northwest, and distance to human occupancy and fishing pressure.

Table A. Detailed information on the 30 permanent stations established by the NCCOS Center for Coastal Fisheries and Habitat Research (CCFHR) in the Dry Tortugas.

Station	Management Strata	Bank	Latitude	Longitude
94	Out	Monument	24.7377996	-82.7934824
1864	Out	Monument	24.7150078	-82.780515
5527	Out	Monument	24.6071167	-82.9948167
5842	Out	Monument	24.5891	-82.9939667
6731	Out	Monument	24.5648662	-82.9083841
6772	Out	Monument	24.5726333	-82.97785
7265	Out	Monument	24.5555	-82.9628
7675	Out	Monument	24.5374167	-82.9510667
11460	Out	Tortugas	24.6167	-83.0933167
12379	Out	Tortugas	24.5984167	-83.0870833
632	Park	Monument	24.723884	-82.8464297
690	Park	Monument	24.722818	-82.8569842
1136	Park	Monument	24.7211957	-82.8746495
2780	Park	Monument	24.6733613	-82.7809035
3120	Park	Monument	24.6577285	-82.942727
3275	Park	Monument	24.6567635	-82.9508205
3926	Park	Monument	24.6402299	-82.7915488
4671	Park	Monument	24.623451	-82.8258409
6108	Park	Monument	24.5878541	-82.8853109
6493	Park	Monument	24.5744955	-82.9014143
1915	Reserve	Monument	24.70315	-82.92815
8233	Reserve	Tortugas	24.6998492	-82.9771463
8924	Reserve	Tortugas	24.6834333	-83.0135833
9042	Reserve	Tortugas	24.6851833	-82.9974667
9162	Reserve	Tortugas	24.6806333	-82.9951
9498	Reserve	Tortugas	24.6782667	-83.0487001
9807	Reserve	Tortugas	24.6609	-83.0467
10105	Reserve	Tortugas	24.6687681	-83.0211125
10262	Reserve	Tortugas	24.6623	-83.0036667
10529	Reserve	Tortugas	24.6595854	-83.0233013

Table B. Species observed at 30 permanent stations from 2001-2005. Common names in bold represent those species included in the fish-environment relationship analyses.

Common Name	Species Name	Common Name	Species Name
Almaco Jack	*Seriola rivoliana*	Cottonwick	*Haemulon melanurum*
Amberjack	*Seriola dumerili*	Creole Wrasse	*Clepticus parrae*
Anchovies	Engraulidae spp.	Cubbyu	*Equetus umbrosus*
Apogon Species	*Apogon* spp.	Damselfish species	Damselfish spp.
Banded Butterflyfish	*Chaetodon striatus*	**Dash Goby**	*Gobionellus saepepallens*
Banded Jawfish	*Opistognathus macrognathus*	**Doctorfish**	*Acanthurus chirurgus*
Bandtail Puffer	*Sphoeroides spengleri*	Dog Snapper	*Lutjanus jocu*
Bar Jack	*Caranx ruber*	Dusky Damselfish	*Stegastes fuscus*
Barred Blenny	*Hypleurochilus bermudensis*	Dusky Flounder	*Syacium papillosum*
Barred Cardinalfish	*Apogon binotatus*	Dusky Jawfish	*Opistognathus whitehursti*
Barred Hamlet	*Hypoplectrus puella*	Eyed Flounder	*Bothus ocellatus*
Beaugregory	*Stegastes leucostictus*	Fairy Basslet	*Gramma loreto*
Belted Sandfish	*Serranus subligarius*	Filefish species	*Monacanthus* spp.
Bicolor Damselfish	*Stegastes partitus*	**Foureye Butterflyfish**	*Chaetodon capistratus*
Bigeye Scad	*Selar crumenopthalmus*	French Angelfish	*Pomacanthus paru*
Black Grouper	*Mycteroperca bonaci*	French Grunt	*Haemulon flavolineatum*
Black Hamlet	*Hypoplectrus nigricans*	Fringed Filefish	*Monacanthus ciliatus*
Blenny species	*Blenny* spp.	Frogfish species	*Antennarus* spp.
Blue Angelfish	*Holacanthus bermudensis*	Gag Grouper	*Mycteroperca microlepis*
Blue Chromis	*Chromis cyanea*	**Goby species**	Goby spp.
Blue Goby	*Ioglossus calliurus*	Goldentail Moray	*Gymnothorax miliaris*
Blue Hamlet	*Hypoplectrus gemma*	**Goldspot Goby**	*Gnatholepis thompsoni*
Blue Parrotfish	*Scarus coeruleus*	Goliath Grouper	*Epinephelus itajara*
Blue Runner	*Caranx crysos*	**Gray Angelfish**	*Pomacanthus arcuatus*
Blue Tang	*Acanthurus coeruleus*	**Gray Snapper**	*Lutjanus griseus*
Bluehead Wrasse	*Thalassoma bifasciatum*	Gray Triggerfish	*Balistes capriscus*
Bluelip Parrotfish	*Cryptotomus roesus*	Graysby	*Epinephelus cruentatus*
Bluestriped Grunt	*Haemulon sciurus*	Great Barracuda	*Sphyraena barracuda*
Boga	*Inermia vittata*	Green Razorfish	*Xyrichthys splendens*
Bonnetmouth	*Enmelichthyops atlanticus*	**Greenblotch Parrotfish**	*Sparisoma atomarium*
Bridled Goby	*Coryphopterus glaucofraenum*	**Grunt species**	*Haemulon* spp.
Brown Chromis	*Chromis multilineata*	Hairy Blenny	*Labrisomus nuchipinnis*
Bucktooth Parrotfish	*Sparisoma radians*	Hamlet species	*Hypoplectrus* spp.
Butter Hamlet	*Hypoplectrus unicolor*	**Harlequin Bass**	*Serranus tigrinus*
Caesar Grunt	*Haemulon carbonarium*	Highhat	*Equetus acuminatus*
Cero Mackerel	*Scomberomorus maculatus*	**Hogfish**	*Lachnolaimus maximus*
Chalk Bass	*Serranus tortugarum*	Honeycomb Cowfish	*Lactophyrs polygonia*
Chub	*Kyphosis secatrix/incisor*	Horse-eye Jack	*Caranx latus*
Cleaning Goby	*Gobiosoma genie*	Hovering Goby	*Ioglossus helenae*
Clown Wrasse	*Halichoeres maculipinna*	Indigo Hamlet	*Hypoplectrus indigo*
Cocoa Damselfish	*Stegastes variabilis*	Inshore Lizardfish	*Synodus foetens*
Colon Goby	*Coryphopterus dicrus*	Jackknife Fish	*Equetus lanceolatus*
Coney	*Epinephelus fulvus*	Jawfish species	*Opistognathus spp.*

Table B (continued). Species observed at 30 permanent stations from 2001-2005. Common names in bold represent those species included in the fish-environment relationship analyses.

Common Name	Species Name	Common Name	Species Name
Knobbed Porgy	*Calamus nodosus*	Saddled Blenny	*Malacoctenus triangulatus*
Lane Snapper	*Lutjanussynagris*	Sailors Choice	*Haemulon parra*
Lantern Bass	*Serranus baldwini*	Sand Diver	*Synodus intermedius*
Lefteye Flounder	Flounder spp.	Sand Perch	*Diplectrum formosum*
Longfin Damselfish	*Stegastes diencaeus*	Sand Tilefish	*Malacanthus plumieri*
Longspine Squirrelfish	*Holocentrus rufus*	**Saucereye Porgy**	*Calamus calamus*
Mahogany Snapper	*Lutjanus mahogoni*	**Scamp**	*Mycteroperca phenax*
Masked Goby	*Coryphopterus personatus*	**Schoolmaster**	*Lutjanus apodus*
Midnight Parrotfish	*Scarus coelestinus*	Scrawled Cowfish	*Lactophrys quadricornis*
Mutton Snapper	*Lutjanus analis*	Scrawled Filefish	*Aluterus scriptus*
Neon Goby	*Gobiosoma oceanops*	Seminole Goby	*Microgobius carri*
Nurse Shark	*Ginglymostoma cirratum*	Sergeant Major	*Abedefduf saxtalis*
Ocean Surgeonfish	*Acanthurus bahianus*	Sharknose Goby	*Gobiosoma evelynae*
Ocean Triggerfish	*Canthidermis sufflamen*	Sharksucker	*Echeneis naucrates*
Orangeback Bass	*Serranus annularis*	**Sharpnose Puffer**	*Canthigaster rostrata*
Orangespotted Goby	*Nes longus*	Shortfin Pipefish	*Cosmocampus elucens*
Parrotfish species	Parrotfish spp.	Silversides	Atherinidae spp.
Pearly Razorfish	*Xyrichthys novacula*	Singlespot Frogfish	*Antenarrius radiosus*
Permit	*Trachinotus falcatus*	**Slippery Dick**	*Halichoeres bivittatus*
Pluma	*Calamus pennatula*	Smallmouth Grunt	*Haemulon chrysargyreum*
Porcupinefish	*Diodon hystrix*	Smooth Trunkfish	*Lactophrys triqueter*
Porgy species	*Calamus spp.*	Spanish Grunt	*Haemulon macrostomum*
Porkfish	*Anisotremus virginicus*	Spanish Hogfish	*Bodianus rufus*
Princess Parrotfish	*Scarus taeniopterus*	Spotfin Butterflyfish	*Chaetodon ocellatus*
Puffer species	Puffer spp.	**Spotfin Hogfish**	*Bodianus pulchellus*
Purple Reeffish	*Chromis scotti*	**Spotted Goatfish**	*Pseudupeneus maculatus*
Queen Angelfish	*Holocanthus ciliaris*	Spotted Moray	*Gymnothorax moringa*
Queen Triggerfish	*Balistes vetula*	**Squirrelfish**	*Holocentrus adscensionis*
Rainbow Wrasse	*Halichoeres pictus*	**Stoplight Parrotfish**	*Sparisoma viride*
Red Grouper	*Epinephelus morio*	Striped Grunt	*Haemulon stiatum*
Red Hind	*Epinephelus guttatus*	**Striped Parrotfish**	*Scarus croicensis*
Redband Parrotfish	*Sparisona aurofrenatum*	**Sunshine Fish**	*Chromis insolata*
Redspotted Hawkfish	*Amblycirrhitus pinos*	Tattler Bass	*Serranus phoebe*
Redtail Parrotfish	*Sparisoma chrysopterum*	**Threespot Damselfish**	*Stegastes planifrons*
Reef Butterflyfish	*Chaetodon sedentarius*	**Tobaccofish**	*Serranus tabacarius*
Reef Croaker	*Odontoscion dentex*	**Tomtate**	*Haemulon aurolineatum*
Reef Squirrelfish	*Holocentrus coruscus*	Trumpetfish	*Aulostomus maculatus*
Reticulate Moray	*Muraena retifera*	Twospot Cardinalfish	*Apogon pseudomaculatus*
Rock Beauty	*Holacanthus tricolor*	Unidentified Species	*Unknown*
Rock Hind	*Epinephelus adscensionis*	**White Grunt**	*Haemulon plumieri*
Rosy Blenny	*Malacoctenus macropus*	White Margate	*Haemulon album*
Rosy Razorfish	*Xyrichthys martinicensis*	Wrasse Basslet	*Liopropoma eukrines*
Round Scad	*Decapterus punctatus*	Wrasse Blenny	*Hemiemblemaria simulus*

Table B (continued). Species observed at 30 permanent stations from 2001-2005. Common names in bold represent those species included in the fish-environment relationship analyses.

Common Name	Species Name	Common Name	Species Name
Yellow Goatfish	*Mulloidichthys martinicus*	Yellowline Goby	*Gobiosoma horsti*
Yellow Jack	*Caranx bartholomaei*	Yellowmouth Grouper	*Mycteroperca interstitialis*
Yellowcheek Wrasse	*Halichoeres cyanocephalus*	Yellowtail Damselfish	*Microspathodon chrysurus*
Yellowfin Grouper	*Mycteroperca venenosa*	Yellowtail Parrotfish	*Sparisoma rubripinne*
Yellowhead Jawfish	*Opistognathus aurifrons*	**Yellowtail Reeffish**	*Chromis enchrysurus*
Yellowhead Wrasse	*Halichoeres garnati*	**Yellowtail Snapper**	*Ocyurus chrysurus*

Appendix III

In 2006, the University of Massachusetts Amherst's Human Dimensions of Marine and Coastal Ecosystems Program was contracted to examine what, if any, wider effects reserve designation has had on the Tortugas for-hire fishing and dive industries. Following initial conversations with operators, it was determined that there were a variety of factors that were relevant to whether fishing and diving businesses made the round trip to the Dry Tortugas area, and that these factors were independent of the establishment of the reserve. Taking these factors into consideration, the group developed a survey instrument to examine the range of possible reasons for not making Tortugas area fishing and diving trips, as well to collect information about previous and current Tortugas activity, and attitudes about the quality of fish and diving pre and post reserve implementation.

Two survey instruments were developed and administered onsite or mailed to 23 individuals associated with 21 for-hire businesses to address the main questions of who is using the area, how often, why, and their views of the quality of fishing and diving in the Tortugas. Both surveys are provided below. See Chapter 7 of this report for the results of the surveys.

Page one of the For-hire Tortugas Diving Survey administered by the University of Massachusetts Amherst's Human Dimensions of Marine and Coastal Ecosystems Program.

2006 Study of Commercial Diving and the Tortugas Ecological Reserve

Human Dimensions of Marine and Coastal Ecosystems
Department of Natural Resources Conservation
University of Massachusetts Amherst

In the following questions, please tell us about your dive for-hire operation. We are interested in learning more about your activities in and around the Tortugas Ecological Reserve.

1. Are you the:
   1. OWNER
   2. OPERATOR
   3. OWNER/OPERATOR

2. Do you operate a:
   1. PARTY BOAT
   2. CHARTER BOAT

3. Did you make for-hire diving trips to the area now designated as the Tortugas Ecological Reserve prior to it being officially established in 2000/2001?
   1. YES – IF YES, please go to Question #4
   2. NO – IF NO, please go to Question #6

Questionnaire # _________

4. For each of the following, how would you rate the quality of diving in or around the Tortugas Ecological Reserve prior to its creation?

	Very poor	Poor	Adequate	Good	Very good
a) Number of fish ………………	1	2	3	4	5
b) Size of fish …………………	1	2	3	4	5
c) Quality of coral ……………	1	2	3	4	5
d) Abundance of coral …………	1	2	3	4	5
e) Species diversity ……………	1	2	3	4	5
f) Conflict with other user groups ...	1	2	3	4	5
g) Other ____________________	1	2	3	4	5

5. On these past trips to the Tortugas Ecological Reserve, what percent of your diving was within what is now the Reserve, and what percent was outside what is now the boundary of the Reserve? (the answers should add to 100)

   ___ % INSIDE THE BOUNDARY OF THE RESERVE
   ___ % OUTSIDE THE BOUNDARY OF THE RESERVE

6. Do you currently make for-hire dive trips to the Dry Tortugas Area?
   1. YES – IF YES, please go to Question #8
   2. NO – IF NO, please go to Question #7

Page two of the For-hire Tortugas Diving Survey administered by the University of Massachusetts Amherst's Human Dimensions of Marine and Coastal Ecosystems Program.

7. Please indicate how important each of the following is as a reason for not currently making for-hire dive trips to the area of the Tortugas Ecological Reserve.

	Not at all important	Slightly Important	Somewhat important	Very important	Extremely important
a) It takes too long to get there ……...	1	2	3	4	5
b) Fuel prices are too high ....…………..	1	2	3	4	5
c) Boat not adequate …….………….….....	1	2	3	4	5
d) Displaced by Ecological Reserve	1	2	3	4	5
e) Unfamiliar with waters ……………..	1	2	3	4	5
f) Not enough clients ....…………..........	1	2	3	4	5
g) Too crowded ……….……………….....	1	2	3	4	5
h) Not enough fish ………………….....	1	2	3	4	5
i) Not enough species diversity ……….	1	2	3	4	5

8. For each of the following, how would you rate the quality of diving near the Tortugas Ecological Reserve today?

	Very poor	Poor	Adequate	Good	Very good
a)Number of fish ………………	1	2	3	4	5
b) Size of fish …………………	1	2	3	4	5
c) Quality of coral ……………	1	2	3	4	5
d) Abundance of coral …………	1	2	3	4	5
e) Species diversity ……………	1	2	3	4	5
f) Conflict with other user groups ...	1	2	3	4	5
g) Other ____________________	1	2	3	4	5

Questionnaire # _________

9. On your current trips to the Tortugas Ecological Reserve, what percent of your diving is within what is now the Reserve, and what percent is outside what is now the boundary of the Reserve? (The answers should add to 100%)

___ % INSIDE THE BOUNDARY OF THE RESERVE
___ % OUTSIDE THE BOUNDARY OF THE RESERVE

10. How many for-hire diving trips did you make to the Tortugas Ecological Reserve during the past 12 months?

___ TRIPS PER YEAR

11. What length trips to the Tortugas Ecological Reserve do you currently offer? (Please circle all that apply)

1. ONE DAY
2. TWO DAY
3. THREE DAY
4. OTHER _________________________________

12. On trips to the Tortugas Ecological Reserve, is there sufficient availability to tie up to a designated mooring buoy?

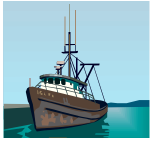
1. YES – IF YES, what percent of the time? ___ %
2. NO

13. To what extent do you feel the creation of the Tortugas Ecological Reserve has improved or harmed the quality of diving in the area?

1. HARMED A GREAT DEAL
2. HARMED SOMEWHAT
3. NO CHANGE
4. IMPROVED SOMEWHAT
5. IMPROVED A GREAT DEAL

The two-page For-hire Tortugas Fishing Survey administered by the University of Massachusetts Amherst's Human Dimensions of Marine and Coastal Ecosystems Program.

2006 Study of Commercial Fishing and the Tortugas Ecological Reserve



Human Dimensions of Marine and Coastal Ecosystems
Department of Natural Resources Conservation
University of Massachusetts Amherst

In the following questions, please tell us about your fishing for-hire operation. We are interested in learning more about your activities in and around the Tortugas Ecological Reserve.

1. Are you the:

   1. OWNER
   2. OPERATOR
   3. OWNER/OPERATOR

2. Do you operate a:

   1. PARTY BOAT
   2. CHARTER BOAT

3. Did you make for-hire trips to the area now designated as the Tortugas Ecological Reserve prior to it being officially established in 2000/2001?

   1. YES – IF YES, please go to Question #4
   2. NO – IF NO, please go to Question #6

Questionnaire # _______

4. For each of the following, how would you rate the quality of fishing in or around the Tortugas Ecological Reserve prior to its creation?

	Very poor	Poor	Adequate	Good	Very good
a) Number of fish ………………	1	2	3	4	5
b) Size of fish …………………	1	2	3	4	5
c) Catch rates ………. ……………	1	2	3	4	5
d) Species diversity ……..…………	1	2	3	4	5
g) Other ____________________	1	2	3	4	5

5. On these past trips to the Tortugas Ecological Reserve, what species of fish did you most often target?

   _______________________ FIRST MOST OFTEN
   _______________________ SECOND MOST OFTEN
   _______________________ THIRD MOST OFTEN

6. Do you currently make for-hire fishing trips to the Dry Tortugas Area?

   1. YES – IF YES, please go to Question #8
   2. NO – IF NO, please go to Question #7

7. Please indicate how important each of the following is as a reason for not currently making for-hire trips to the area of the Tortugas Ecological Reserve.

	Not at all important	Slightly Important	Somewhat important	Very important	Extremely important
a) It takes too long to get there ……...	1	2	3	4	5
b) Fuel prices are too high ...…………..	1	2	3	4	5
c) Boat not adequate …….………….....	1	2	3	4	5
d) Displaced by Ecological Reserve	1	2	3	4	5
e) Unfamiliar with waters ……………..	1	2	3	4	5
f) Not enough clients ....…………..........	1	2	3	4	5
g) Too crowded ……….…………….....	1	2	3	4	5
h) Not enough fish ………………….....	1	2	3	4	5
i) Not enough species diversity ……….	1	2	3	4	5

8. For each of the following, how would you rate the quality of fishing near the Tortugas Ecological Reserve today?

	Very poor	Poor	Adequate	Good	Very good
a)Number of fish ………………..……	1	2	3	4	5
b) Size of fish ……………...………	1	2	3	4	5
c) Catch rates ……………………	1	2	3	4	5
d) Species diversity ……..…………	1	2	3	4	5
g) Other ____________________	1	2	3	4	5

Questionnaire # _______

9. Do you routinely fish near the boundaries of the Tortugas Ecological Reserve?

   1. YES
   2. NO

10. How many for-hire fishing trips did you make to the Tortugas Ecological Reserve during the past 12 months?

    ___ TRIPS PER YEAR

11. What length trips to the Tortugas Ecological Reserve do you currently offer? (Please circle all that apply)

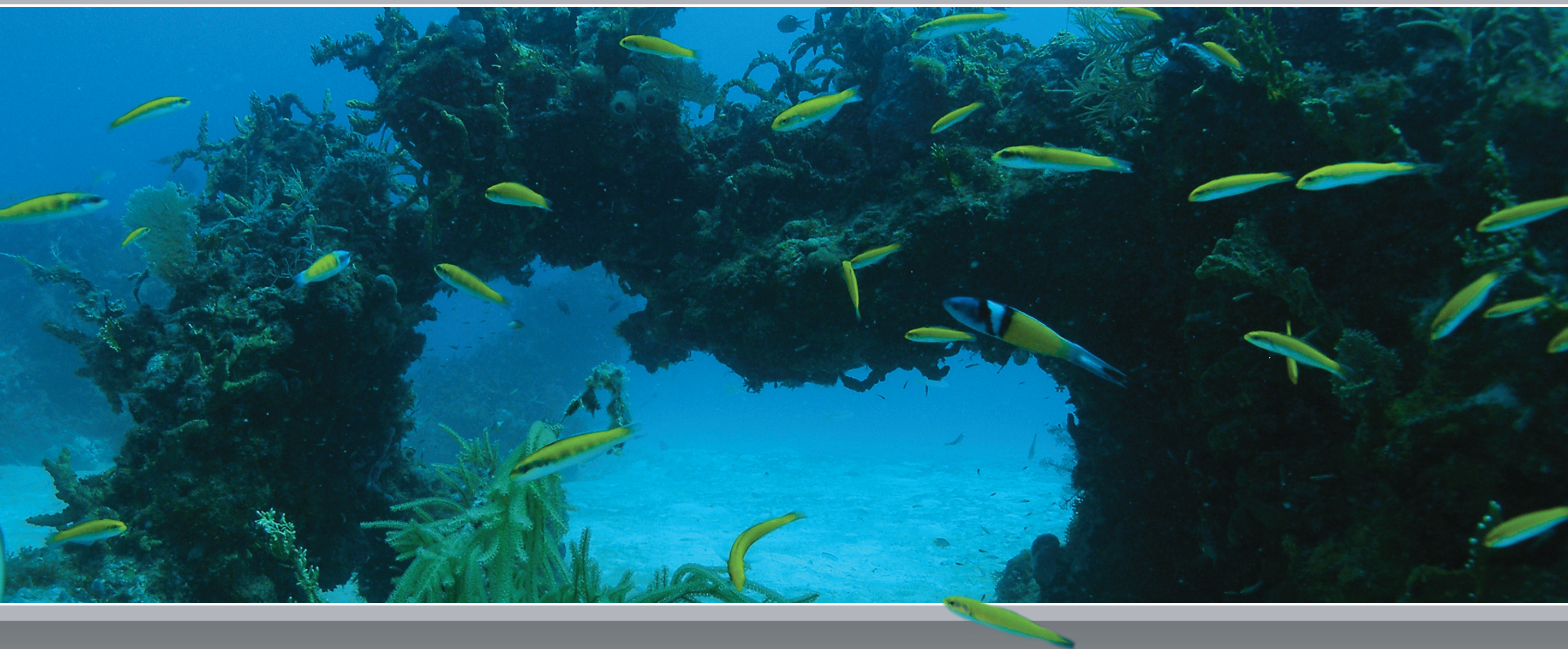
    1. ONE DAY
    2. TWO DAY
    3. THREE DAY
    4. OTHER ________________________________

12. On current trips to the Tortugas Ecological Reserve, what species of fish do you most often target?

    _______________________ FIRST MOST OFTEN
    _______________________ SECOND MOST OFTEN
    _______________________ THIRD MOST OFTEN

13. To what extent do you feel the creation of the Tortugas Ecological Reserve has improved or harmed the quality of fishing in the area?

    1. HARMED A GREAT DEAL
    2. HARMED SOMEWHAT
    3. NO CHANGE
    4. IMPROVED SOMEWHAT
    5. IMPROVED A GREAT DEAL



U.S. Department of Commerce

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